GEOLOGICAL SURVEY OF ALABAMA

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Final Report

HYDROGRAPHIC NUMERICAL MODEL INVESTIGATION AND ANALYSIS OF AN OFFSHORE SAND RESOURCE SITE FOR USE IN BEACH NOURISHMENT PROJECTS ON DAUPHIN ISLAND, ALABAMA

by

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Prepared by the Geological Survey of Alabama in cooperation with the Department of Chemical Engineering, University of Alabama, in fulfillment of U.S. Department of the Interior, Minerals Management Service Cooperative Agreement No. 14-35-0001-30781

Tuscaloosa, Alabama
1997

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EXECUTIVE SUMMARY

Since 1986, the Minerals Management Service of the U. S. Department of the Interior has directed the Gulf Task Force, composed of representatives of the states of Alabama, Mississippi, Louisiana, and Texas, to assess the occurrence and economic potential of hard mineral (nonfuel) resources in the Exclusive Economic Zone of those states. Sand and gravel, shell, and heavy minerals were the prominent hard minerals identified in the Gulf of Mexico Exclusive Economic Zone, with sand being identified as the most abundant mineral and having the highest near-term leasing potential.

The primary goal of the present study by the Geological Survey of Alabama and the University of Alabama, Department of Chemical Engineering is to conduct numerical modeling studies of sand resource target area 4 and begin numerical modeling studies of the southeastern shoreline of Dauphin Island, to provide information needed to develop a beach nourishment project for Dauphin Island. The Dauphin Island modeling effort will continue in the next study year. The numerical models will utilize a modeling database assembled by Hummell and Smith (1995, 1996), and new databases produced by the Geological Survey of Alabama and the University of Alabama, Department of Chemical Engineering in the present study.

The study tasks of the Geological Survey of Alabama include continuing to use several forums to network with numerous individuals and agencies as a prelude to making recommendations toward development of Dauphin Island beach nourishment projects that would utilize the sand resource body in sand resource target area 4. In addition, the Geological Survey of Alabama continued the modeling database building process by conducting a preliminary investigation of historic hurricanes and tropical storms that have affected coastal Alabama; historic ship channel dredging and dredged material disposal in the Gulf of Mexico; and producing a bathymetric and sediment budget (bathymetric differencing) maps for the study area from 1732 to 1997. These databases would be used to verify numerical modeling results and develop case histories for testing the numerical models. Further, the Geological Survey of Alabama and the University of Alabama, Department of Chemical Engineering worked together to identify and assess the numerical models that might be supported by the modeling database, the existence of other models and additional databases needed to adapt them to these systems, and the outcomes that would form the goals of this project based on the model and database decisions identified. The Geological Survey of Alabama formulated goals, objectives, needs, and questions that must be satisfied in the numerical modeling study; evaluated the completed modeling database and made recommendations regarding the kinds of modeling output that are desired to meet initial goals and objectives; and participated in ranking the available models that are supported by the database, and making selections based on meeting stated goals and objectives.

Historic records show that over the period 1700-1997, 55 hurricanes and 16 tropical storms affected the Alabama coast. However, only seven to 15 of the 22 hurricanes and one tropical storm, which caused more than minimal impact on coastal Alabama, are thought to have changed the geography and bathymetry of the study area.

Mobile Bay has an average depth of 10 feet, and originally had a controlling depth of 5 feet over the bar at the mouth of the Mobile-Tensaw River system at the Port of Mobile. The natural controlling depth over the entrance bar to Mobile Bay at Main Pass was 23 feet. The federal government began channel improvements in 1826, and through the years the channel depths and widths kept pace with the increasing size of vessels using the Port of Mobile.

The 1732 to 1997 bathymetric and bathymetric differencing maps, produced from historic hydrographic surveys and nautical charts, and historic illustrations and documents, chronicle a cycle of geographical and bathymetric change spanning the past 294-year history of the study area. The interplay between coastal geography, bathymetry, ebb-flood tidal channel dredging, scouring, and filling, punctuated by hurricanes and tropical storms, dictates nearshore sediment transport pathways, Gulf of Mexico wave orientation, patterns of shoreline erosion and accretion, and tidal current velocity.

Except for brief periods of erosion or deposition that caused bathymetric changes of a few feet, the overall bathymetry of sand resource target area 4 has not changed appreciatively over the past 265 years.

The results of this study show that the depth and length of the ebb-flood tidal channel are the primary factors in determining nearshore sediment transport pathways. In general, when the channel is deep and extends from Morgan Peninsula to the southern apex of the ebb-tidal delta of Mobile Bay, the channel acts as a barrier to sediment transport from the Morgan Peninsula Gulf of Mexico shoreline across Main Pass to Dauphin Island Gulf of Mexico shoreline. In this case, the dominant nearshore sediment transport pathway is from Morgan Peninsula southward, along the eastern margin of the ebb-tidal delta of Mobile Bay, around the southern apex of the delta, and northwestward, along the western margin of the delta (and Pelican and Sand Islands) to Dauphin Island. When the ebb-flood tidal channel is relatively shallow, and short or discontinuous, nearshore sediment transport is from Morgan Peninsula westward, through Pelican Bay, to Dauphin Island. Most of the time over the past 265 years, both nearshore sediment transport pathways have been operational, but always one pathway is dominant over the other. During times when the nearshore sediment transport pathway from Morgan Peninsula is essentially west to Dauphin Island, most of the southeastern shoreline of Dauphin Island is in a state of accretion. Sediment starvation, brought about by the nearshore sediment transport pathway following the margin of the ebb-tidal delta of Mobile Bay, results in a state of erosion for most of the southeastern Dauphin Island shoreline. When both pathways are active, even though the ebb-tidal delta of Mobile Bay pathway is dominant, there may be enough sediment in transport along the direct, westward route, to keep the southeastern Dauphin Island shoreline stable or accretionary.

Sediment obtained from the Morgan Peninsula littoral drift system and tidal current erosion of channel margins is used by the study area hydrographic system to infill the ebb-flood tidal channel. Hurricanes, and dredging of the Mobile Bay entrance channel over the past 74 years, is responsible for deepening and lengthening the ebb-flood tidal channel.

Based on criteria developed by the Geological Survey of Alabama and the University of Alabama, GENESIS (**Gene**ralized Model for **Si**mulating **S**horeline Change) was initially selected as the numerical model that might best serve the needs to model the hydrographic and sediment transport systems of sand resource and nearshore southeastern Dauphin Island areas. After accomplishing the initial steps toward making GENESIS operational, and with further research on the numerical model, it was concluded by the University of Alabama, Department of Chemical Engineering, that GENESIS would not be robust enough to handle the complex hydrographic and sediment transport systems found in the study area.

The second choice, a multi-layered, three-dimensional model, is currently being evaluated by the University of Alabama, Department of Chemical Engineering. Once operational, the numerical model will be used to simulate the present-day hydrographic and sediment transport systems of sand resource target area 4 and trhe southeastern shore of Dauphin Island. The bathymetric and bathymetric differencing database, preliminary historic channel dredge and dredged material disposal information, and preliminary historic tropical storm and hurricane data, will be used by the University of Alabama, Department of Chemical Engineering to develop a working numerical model of sand resource in the study areas. Applicable needs and questions listed above will then be addressed by working numerical modeling studies by the University of Alabama, Department of Chemical Engineering, and the Geological Survey of Alabama.

The Geological Survey of Alabama makes the following recommendations to the University of Alabama, Department of Chemical Engineering.

Those historic hurricanes identified in the present study by the Geological Survey of Alabama as having more than a minimal impact on coastal Alabama should be researched more extensively by the Geological Survey of Alabama to provide a detailed account of each storm. This information would be useful in developing a working numerical model that incorporates periodic hurricanes.

During the Geological Survey of Alabama’s preliminary investigation of historic channel dredging and dredged material disposal in coastal Alabama, an extensive collection of documents were located that can provide additional information. It is recommended that these documents be reviewed by the Geological Survey of Alabama to obtain any dates and locations of historic dredging and dredged material disposal in the study area.

In the aftermath of Hurricane Danny, it is recommended that the Geological Survey of Alabama conduct ground surveys to update erosion rates and the estimates of sand volumes required to restore and stabilize southeastern Dauphin Island eroding shoreline segments delineated by Parker and others (1993). In addition, the numerical modeling of southeastern Dauphin Island shoreline will require a synthesis of the entire shoreline profile database into a form that can be used by the numerical model.

The Geological Survey of Alabama recommends that several additional sea floor samples and vibracores be collected by the Geological Survey of Alabama to determine the impact of spring 1997 Mobile Bay sediment plumes and Hurricane Danny on the sand resource body in sand resource target area 4.

ACKNOWLEDGMENTS

I would like to thank Marianne Donnell, Maps Department, Robert Manning Strozier Library, The Florida State University, Tallahassee, Florida, and Dr. Andrea Watson, Reference Librarian, W.S. Hoole Special Collections Library, The University of Alabama, Tuscaloosa, Alabama, for assistance in obtaining historic maps used in this project. I wish to thank Paul Bradley of the U.S. Army Corps of Engineers, Mobile District, for compiling historic channel dredge and dredge material disposal records for the study area.

INTRODUCTION

OBJECTIVES

Hard mineral resources in the Exclusive Economic Zone (EEZ) have been the target of much research in recent years due to a growing need to delineate additional supplies of sand and gravel, shell, heavy minerals, phosphates and other economic minerals. In 1986, the U.S. Department of the Interior, Minerals Management Service (MMS) established the Gulf Task Force composed of representatives of Alabama, Mississippi, Louisiana, and Texas to assess the occurrence and economic potential of hard mineral (nonfuel) resources in the EEZ, offshore Alabama, Mississippi, Louisiana, and Texas based on available data. Sand and gravel, shell, and heavy minerals were the prominent hard minerals identified in the Gulf of Mexico EEZ. Sand was identified as being the most abundant mineral and having the highest near-term leasing potential. Based on these results, ensuing studies by the task force have been directed at characterizing high quality sand deposits for use in beach restoration projects.

In 1993, the Geological Survey of Alabama (GSA) identified and characterized five potential sites of high-quality clean sand deposits in the EEZ, offshore Alabama, and determined the development potential for use in beach nourishment of specific eroding shoreline segments in Alabama's coastal area (figs. 1, 2). Characteristics of the offshore sand deposits were compared with competing onshore deposits to identify the most suitable material for use in beach nourishment projects. In addition, a preliminary evaluation of the physical and biological environmental impacts was completed. The Gulf of Mexico shoreline along the southeastern portion of Dauphin Island was determined by GSA to have the highest prioritization of all eroding

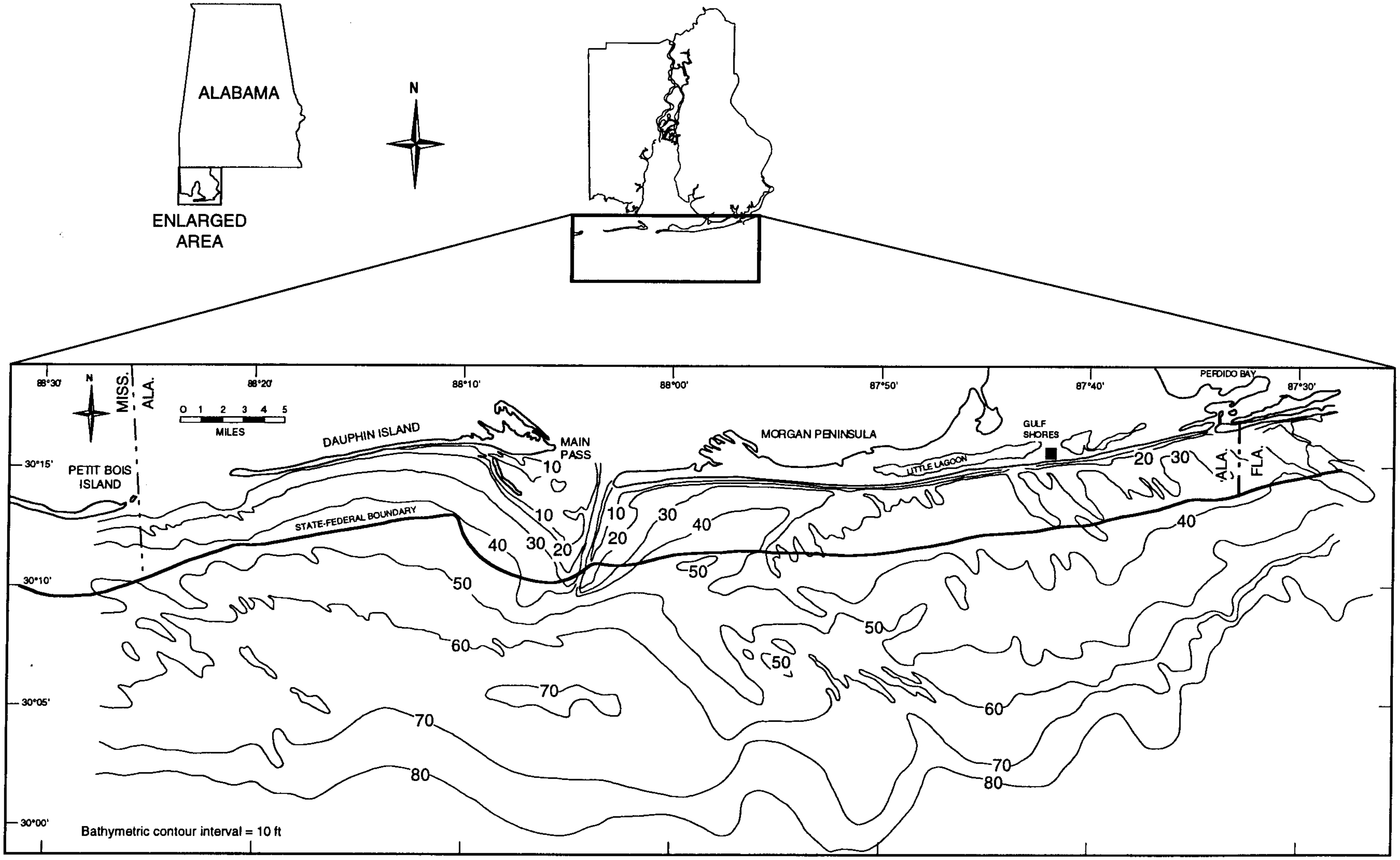


Figure 1.--Map of the Alabama EEZ (modified from Parker and others, 1993).

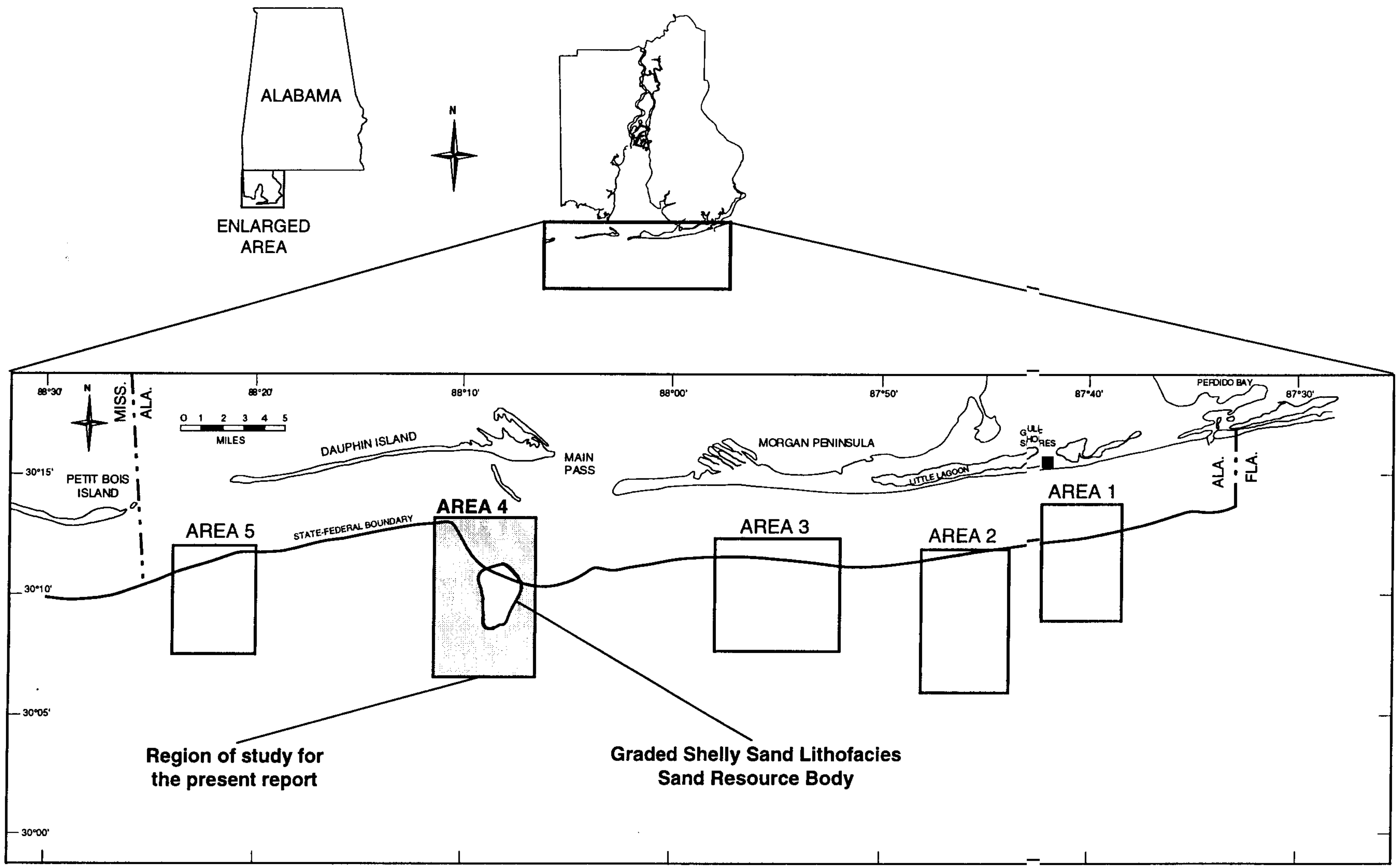


Figure 2.--Index map of EEZ sand resource target areas showing site of the Gradeq Shelly Sand Lithofacies sand resource body (modified from Parker and others, 1993).

shoreline segments. One of the five delineated sand resource target areas, area 4, was determined by MMS to be the most economical of the target areas for beach replenishment of these portions of Dauphin Island (fig. 2).

The GSA continued the goals of the Gulf Task Force with a study by Hummell and Smith (1995). The primary objective for this study was to better characterize area 4, which appears to have near term lease potential for use in beach nourishment projects on Dauphin Island.

Research by Hummell and Smith (1995) focused on the acquisition of additional data to determine shoreline loss for the period 1985-93 along eroding Dauphin Island Gulf of Mexico shoreline segments. This data combined with shoreline loss determinations made by Parker and others (1993) for the period 1955-85, resulted in an estimation of the sand volume required to restore selected segments of Dauphin Island shoreline to their 1955 position.

Parker and others (1993) used only a few vibracores to delineate the distribution and physical characteristics of the sand deposit in area 4. Much of the sand is associated with the distal margin of an ebb-tidal delta of Mobile Bay. Research by the senior author on the ebb-tidal delta (Hummell, 1990) and nearshore Gulf of Mexico (Hummell, 1996), indicates that Holocene sediment geometry in area 4 is related to bathymetry. In addition, ebb-tidal sand bodies (potential target sands) are 'tongue-shaped' or 'sheet-like' deposits interbedded with muddier ebb-tidal delta deposits (Hummell, 1996). Mobile Bay ebb-tidal delta stratigraphy and facies relationships are complex, especially adjacent to the ebb-flood tidal channel and along the distal margin of the delta where ebb-tidal delta deposits interfinger with nearshore Gulf of Mexico shelf sediments (fig. 3) (Hummell, 1996).

In light of these findings, it was necessary to conduct a detailed geological evaluation of area 4 to identify and characterize specific target sand bodies

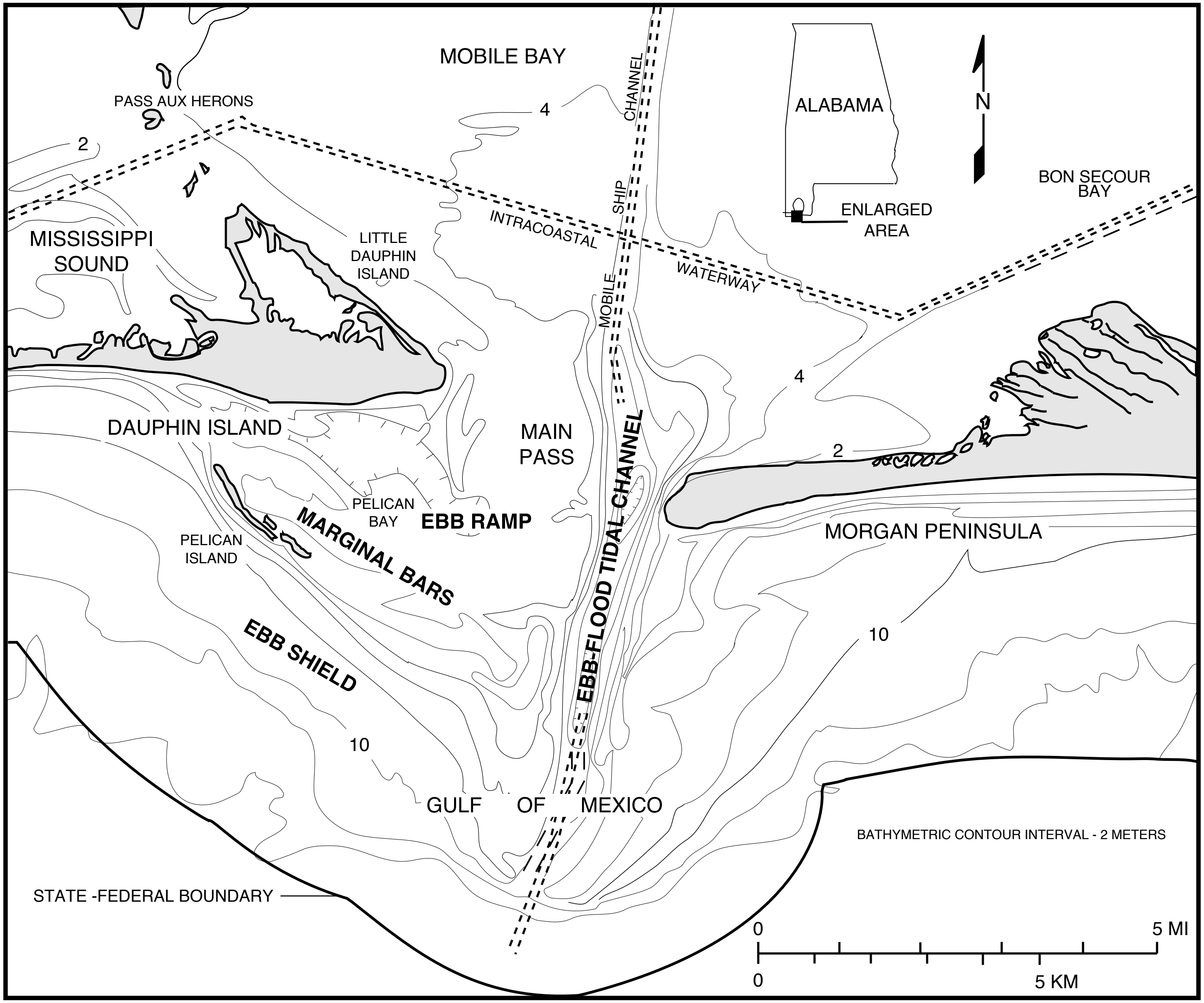


Figure 3.--Geomorphology of the ebb-tidal delta of Mobile Bay (modified from Hummell, 1996).

before initiating sand dredging to ensure a cost-effective program. Hummell and Smith (1995) collected additional vibracores and combined this new data with pre-existing vibracores, foundation borings, and seismic data to more accurately describe and delineate the sand resources in area 4.

In addition, Hummell and Smith (1995) developed a more complete evaluation of benthic and nektonic organisms that live in area 4. This information would provide a basis for conducting a detailed sea bottom biological investigation of the target sand bodies to determine the impact dredging activities would have on inhabiting organisms.

As a result of their investigation, Hummell and Smith (1995) recommended that before a dredge operation can take place, additional vibracores need to be collected from the sand resource body to better delineate sand body geometry and granulometric homogeneity to ensure a cost-effective program of sand resource recovery. In addition, they recommended that the erosion and sediment transport systems for area 4 and southeastern Dauphin Island shoreline should be computer modeled to predict the possible consequences of mining and application of sand. Also, communication (networking) with local officials, and state and federal agencies with jurisdiction in coastal Alabama is vital to development of recommendations pertinent to a demonstration project, environmental impact study, and a full scale shoreline nourishment project.

Hummell and Smith (1996) is a synthesis of new vibracore and shoreline profile data and the findings of Hummell and Smith (1995). The authors consider a synthesized, stand-alone report to be more useable and instructive than two related but separate reports. Included in the report are the results of a further investigation of the area 4 sand resource body discovered by Hummell and Smith (1995). In addition, pre-existing wind, wave, current, tide, and bathymetric data was collected and evaluated for the sand resource site and eroding shoreline segments on eastern

Dauphin Island. Analysis of these data in conjunction with previous hydrographic studies form the basis for making recommendations concerning the nature of future numerical modeling studies of the physical system associated with area 4 and southeastern Dauphin Island shoreline. Several forums permitted extensive networking with numerous individuals and agencies as a prelude to making recommendations toward development of a beach nourishment project that would utilize the sand resources body for beach nourishment projects on Dauphin Island.

The present report is a sediment transport study of a region that includes the ebb-tidal delta of Mobile Bay, Main Pass, southeastern shoreline of Dauphin Island, area 4, and nearshore Gulf of Mexico continental shelf (fig. 4). The study generated a database of bathymetric and sediment budget (bathymetric differencing) maps dating from 1732 to 1997. These maps were constructed using depth measurements in the form of soundings, obtained from historic maritime surveys. The addition of information derived from an investigation of historic hurricanes that have affected coastal Alabama, U.S. Army Corps of Engineers Mobile Ship Channel dredge records, historic documents and eyewitness accounts, and sea floor sediment texture maps from Hummell and Smith (1996) are databases that would be needed to develop a working numerical model of area 4, verify modeling results, and construct case studies to fine-tune the model. The databases will be used in part to initiate development of a numerical model for southeastern Dauphin Island shoreline. Further, pre-existing and new beach profile data, information derived from a further investigation of historic hurricanes that have impacted coastal Alabama, and additional historic channel dredging and dredged material disposal, will be utilized in numerical modeling studies of southeastern Dauphin Island shoreline and nearshore Gulf of Mexico. Several forums permitted extensive networking

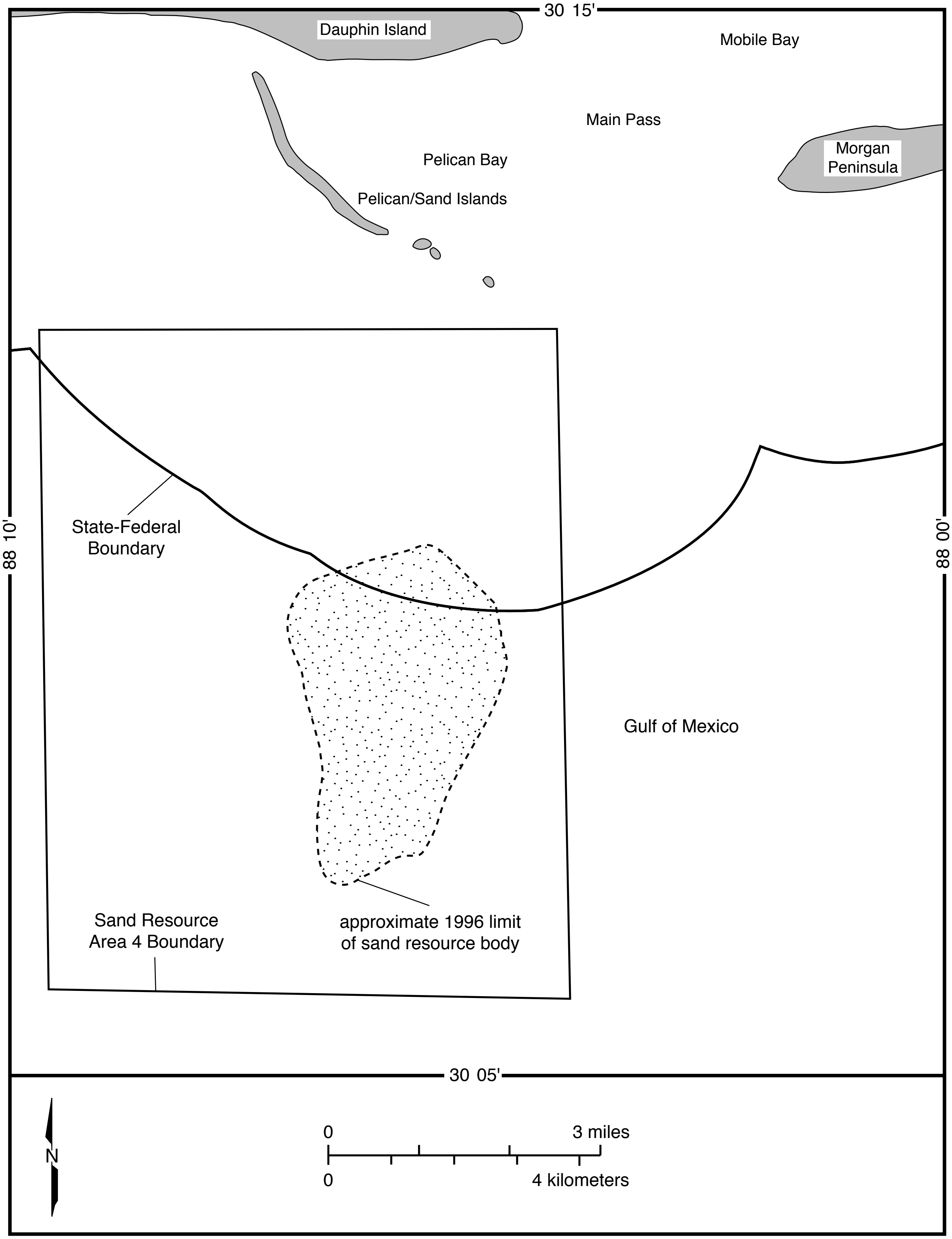


Figure 4.--Map of study area.

with numerous individuals and agencies as a prelude to making recommendations toward development of a beach nourishment project that would utilize the sand resources body in area 4.

TASKS ACCOMPLISHED AND APPROACH FOLLOWED

The objectives of this study were to be accomplished through completion of three tasks designed to continue the networking process with pertinent agencies as an information gathering mechanism for development of a recommendation for a beach nourishment project: identify and characterize the nature of the modeling database, begun in year one of this project, that will form the starting point for identification of a suitable numerical model or models; select the appropriate physical models that might exist and determine those that might be appropriate for the given data base, computational limitations or other constraints; and arrive at an appropriate numerical model that describes the system (first area 4, followed later in the area of Dauphin Island) and allows for the full support of a beach nourishment program addressing sand removal and beach nourishment objectives. The plan of study was designed to ensure that a coordinated effort was maintained between the GSA and the University of Alabama, Department of Chemical Engineering (ChE) throughout the project that resulted in fulfilling the project objectives and specific identified tasks. The GSA was solely responsible for some tasks; other tasks are the sole responsibility of ChE; and some tasks are the joint responsibility of GSA and ChE. This report contains only the findings that were derived by GSA for tasks that are the sole responsibility of GSA, and the GSA's portion of tasks that are the joint responsibility of GSA and ChE. These tasks, the responsibility for each (GSA, ChE, or both GSA and ChE), and the approach utilized for each, include the following:

1. Networking. The approach utilized by GSA was to continue to use several established lines of communication to dialogue with local government, state, and federal agencies concerning past, present, and future work efforts by the GSA and MMS toward a beach nourishment project for Dauphin Island. This dialogue permits the exchange of information and ideas between groups addressing Alabama coastal erosion issues. In addition, the networking has established a partnership between groups that will ultimately be involved in a Dauphin Island demonstration project. Expected results of this interaction would include acquisition of available pre-existing geoscience data to support research on sedimentary and erosional regimes, and numerical modeling and assessment of the physical systems of area 4 and southeastern Dauphin Island shoreline; information and recommendations concerning dredging technology and methodology; opinions and suggestions regarding a beach nourishment project; and recommendations concerning the nature of an environmental impact statement.

Networking includes groups such as the U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, Alabama Department of Environmental Management, Alabama Department of Economic and Community Affairs, Dauphin Island Sea Lab, local coastal governments, regional planning commissions, universities, and agencies with biological experience such as the Alabama Department of Conservation and Natural Resources.

2. Completion of modeling database. In the first year of study, the process of collecting and evaluating available pre-existing geoscience data for area

4 and for the eroding shoreline segments on southeastern Dauphin Island was begun by GSA to assess the potential impacts of sand dredging and beach replenishment projects. The GSA worked with ChE to continue the modeling database building process during this second year by obtaining and evaluating any available relevant pre-existing geoscience data within the budget constraints of the study. The ChE, in conjunction with GSA, evaluated the need for additional data that any candidate numerical model may require to be functional and to meet project goals. Recommendations in the form of state-of-the-art numerical models and appropriate database needs will be useful in evaluating both computational and physical modeling capabilities in setting the goals that might be achievable.

3. Physical system modeling. The GSA and ChE worked together to identify and assess the numerical models that might be supported by the modeling database, the existence of other numerical models and additional databases needed to adapt them to these systems, and the outcomes that might form the goals of this project based on the model and database decisions identified.

In addition, GSA formulated goals, objectives, needs, and questions that must be satisfied in the numerical modeling study; evaluated the completed modeling database and made recommendations regarding the kinds of modeling output that is desired to meet initial goals and objectives; participated in ranking the available models that are supported by the modeling database and making selections based on meeting stated goals and objectives; selected case studies designed to test the validity of the selected model; participated in evaluating the results of modeling studies; investigated changes that might be made in the model that would improve the ability of the model to approximate system behavior; participated in testing the model for a series of system variable changes deemed applicable to the physical system (including current flow, sediment loading, and wind forces); draw conclusions and make recommendations as to the type of beach nourishment projects that can be evaluated using the developed models; and determine the need for continued modeling studies or studies to collect additional data.

NETWORKING

MINERALS MANAGEMENT SERVICE COORDINATION MEETING

The GSA hosted the *MMS Coordination Meeting: Environmental Survey of Identified Sand Resource Sites Offshore Alabama* on April 18, 1997. Participants included Richard L. Hummell, GSA; Dr. Gary C. April, ChE; Barry S. Drucker, MMS; Alvin L. Jones, MMS; Dr. Mark R. Byrnes, Aubrey Consulting, Incorporated, Woods Hole Group; Dr. Richard M. Hammer, Continental Shelf Associates, Incorporated; and Dr. Barry A. Vittor, Barry A. Vittor and Associates, Incorporated.

The purpose of the three-hour scientific and technical meeting was to coordinate research between research groups, exchange scientific information and opinion between research groups, and avoid redundancy of research efforts and tasks. Presentations were given on past studies completed by GSA, current studies by GSA and ChE, and MMS's sand resources environmental and ecological assessment study.

TECHNICAL INTERAGENCY COMMITTEE MEETING

The author attended a Technical Interagency Committee meeting held on June 5, 1997, in Mobile, Alabama. In an effort to increase members' knowledge about the gas industry in coastal Alabama, two speakers were invited by the committee to give presentations. Donnie Ellis, Mobil Exploration and Producing U.S., Incorporated, gave a presentation on the history of the natural gas industry in coastal Alabama, how industry explores for and produces natural gas, and the safety systems and measures employed by industry. Ralph Hellmich, State Oil and Gas Board of the state of Alabama, presented an overview of the gas industry infrastructure in coastal Alabama; discussed the State Oil and Gas Board mandate; outlined the state of Alabama industry rules, regulations, policy, and procedures; predicted the future course of industry in coastal Alabama; and explained what the royalties generated by Alabama state waters gas production means to the state of Alabama.

COASTAL ALABAMA EXCURSION

The author and Dr. Donald F. Oltz, Alabama State Geologist and Oil and Gas Board Supervisor, traveled in south Alabama June 30 to July 2, 1997, to meet with faculty/staff of the State Oil and Gas Board Field Office, Mobile; Weeks Bay National Estuarine Research Reserve, Baldwin County; Mobile Bay National Estuary Program, Fairhope; and Dauphin Island Sea Laboratory, to discuss the sand resources project and related research.

HURRICANE DANNY

Hurricane Danny, a category 1 hurricane (Saffir/Simpson Hurricane Scale - table 1), impacted coastal Alabama July 18-20, 1997. The author conducted coastal shoreline damage assessment ground surveys during July 31 through August 1, 1997, and August 6-7, 1997. These surveys provided an opportunity to discuss the sand resources project and the impact of Hurricane Danny with the public, local officials, and the media.

In general, property, beach, and coastal eolian dune damage along the immediate coast caused by the hurricane was minimal and localized. A less than 5-foot (ft) high storm surge, combined with favorable storm wind and wave directions, were responsible for the low hurricane impact on coastal Alabama. However, sections of Gulf of Mexico shoreline sustained extensive erosion from storm wave and wind activity that preceded the hurricane. These pre-storm conditions resulted in the loss of several tens of feet of dry beach, and in some places, the first line of coastal eolian foredunes. Sand from the beach shoreface and foredunes were transported seaward by storm waves, and added to the storm berm forming at the toe of the beach.

Bluffs along the northeast shoreline of Mobile Bay experienced debris slides, mud flows, and slumps due to undercutting of the bluff by storm waves, erosion by runoff from the torrential rainfall, and saturation of bluff sediments with infiltrated rainwater. The retreat of the bluffs damaged dozens of houses located at the bluff edge, and resulted in the loss of many more decks, patios, and stairways that connect the houses with boat docks below.

Table 1.--Saffir/Simpson hurricane scale (modified from U.S. Army Corps of Engineers, 1981).

Category	Central Pressure		Winds	Storm Surge	Damage
	in millibars	in inches	in miles per hour	in feet	
1	greater than 980	greater than 28.94	74 - 95	4 - 5	minimal
2	965 - 979	28.50 - 28.91	96 - 110	6 - 8	moderate
3	945 -964	27.91 - 28.47	111 - 130	9 - 12	extensive
4	920 - 944	27.17 - 27.88	131 - 155	13 - 18	extreme
5	less than 920	less than 27.17	greater than 155	greater than 18	catastrophic

GEOGRAPHIC SETTING

INTRODUCTION

Area 4 is part of the east Louisiana-Mississippi-Alabama Shelf (fig. 5), a triangular-shaped region that includes parts of offshore Louisiana, Mississippi, Alabama and northwest Florida (Parker, 1990). The shelf extends from the Mississippi River delta eastward to the De Soto Canyon and from the southern shorelines of the Mississippi-Alabama-northeast Florida barrier islands to the 650-ft (200-meter) isobath (Parker, 1990). Area 4 includes that part of the shelf from Main Pass to just west of Pelican Island and from south of Pelican Island out to about the 60-ft isobath (fig. 6). The narrow shoreface of Dauphin Island forms the northern boundary of the shelf. The break in slope between the shelf and shoreface here occurs at approximately the 19.5-ft isobath. The shoreface gradient south of Dauphin Island is approximately 53 feet per mile (ft/mi) and the shelf gradient from the shoreface of Dauphin Island to the state-federal boundary is approximately 9 ft/mi. The surface within the study area is relatively smooth and featureless interrupted by the broad topographic high representing the ebb-tidal delta of Mobile Bay (fig. 6). Directly north of the study area is Dauphin Island, Pelican Island and two large estuary systems, Mississippi Sound and Mobile Bay.

Dauphin Island is the easternmost island in the Mississippi-Alabama barrier chain that separates Mississippi Sound from the Gulf of Mexico (fig. 7). The Island is approximately 15 mi long and varies from 1.6 mi to 0.25 mi wide with elevations on the eastern end of the Island generally between 5 and 10 ft, with the exception of an east-west trending coastal sand dune located north of the beach, which rises to as much as 45 ft (Hardin and others, 1976). The western

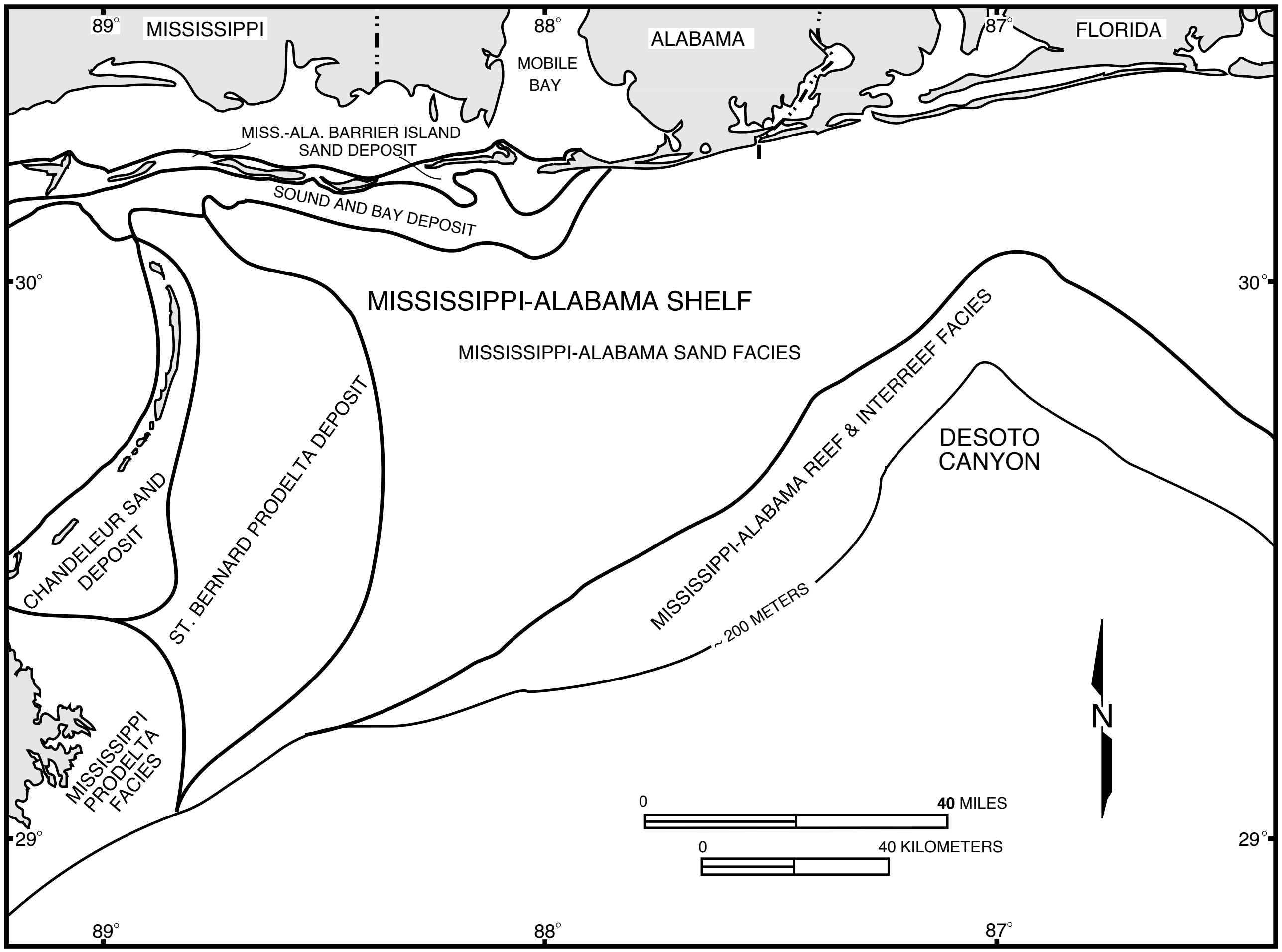


Figure 5.--Sedimentary facies on the Mississippi-Alabama shelf (modified from Ludwick, 1964; Boone, 1973).

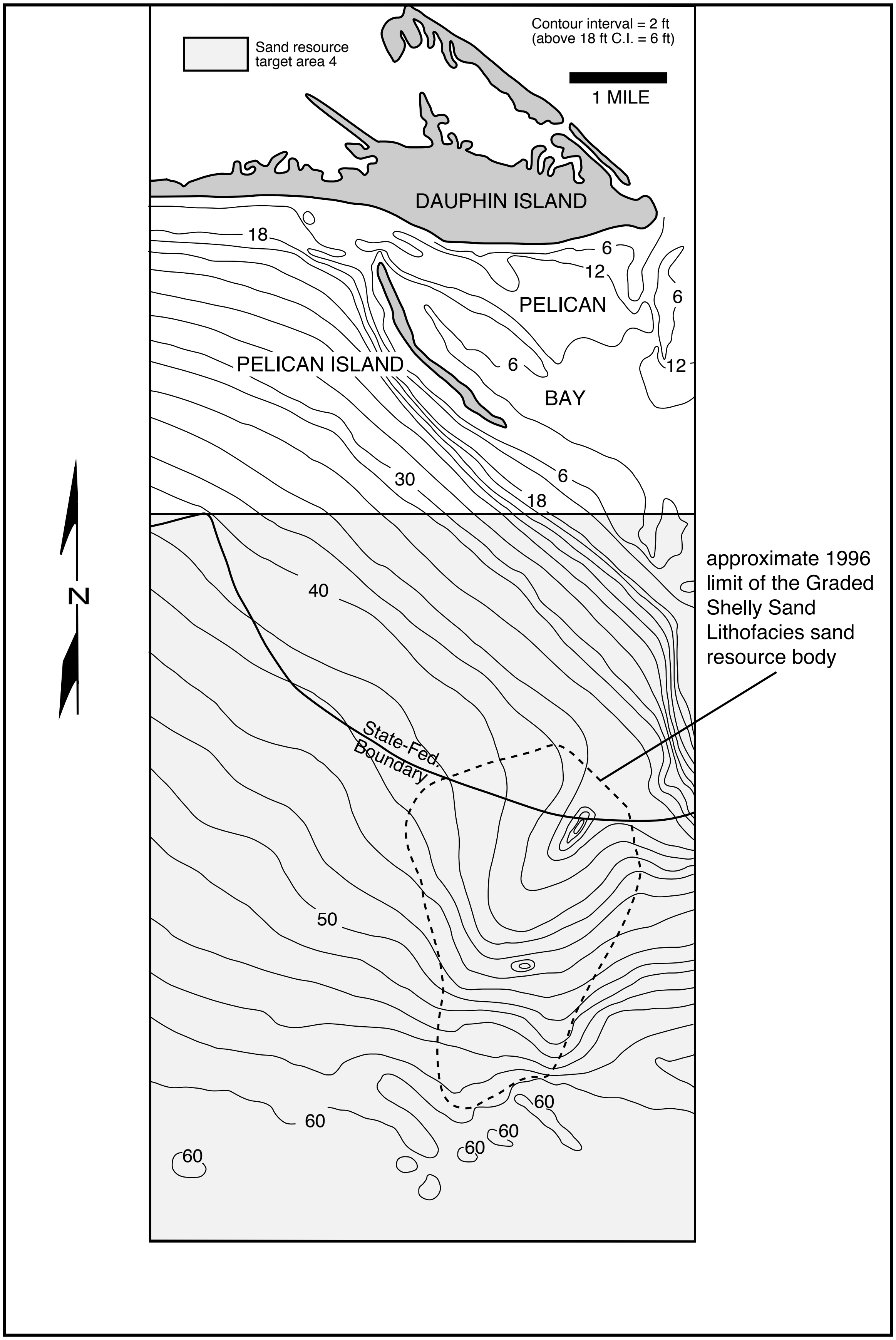


Figure 6.--Map of sand resource target area 4.

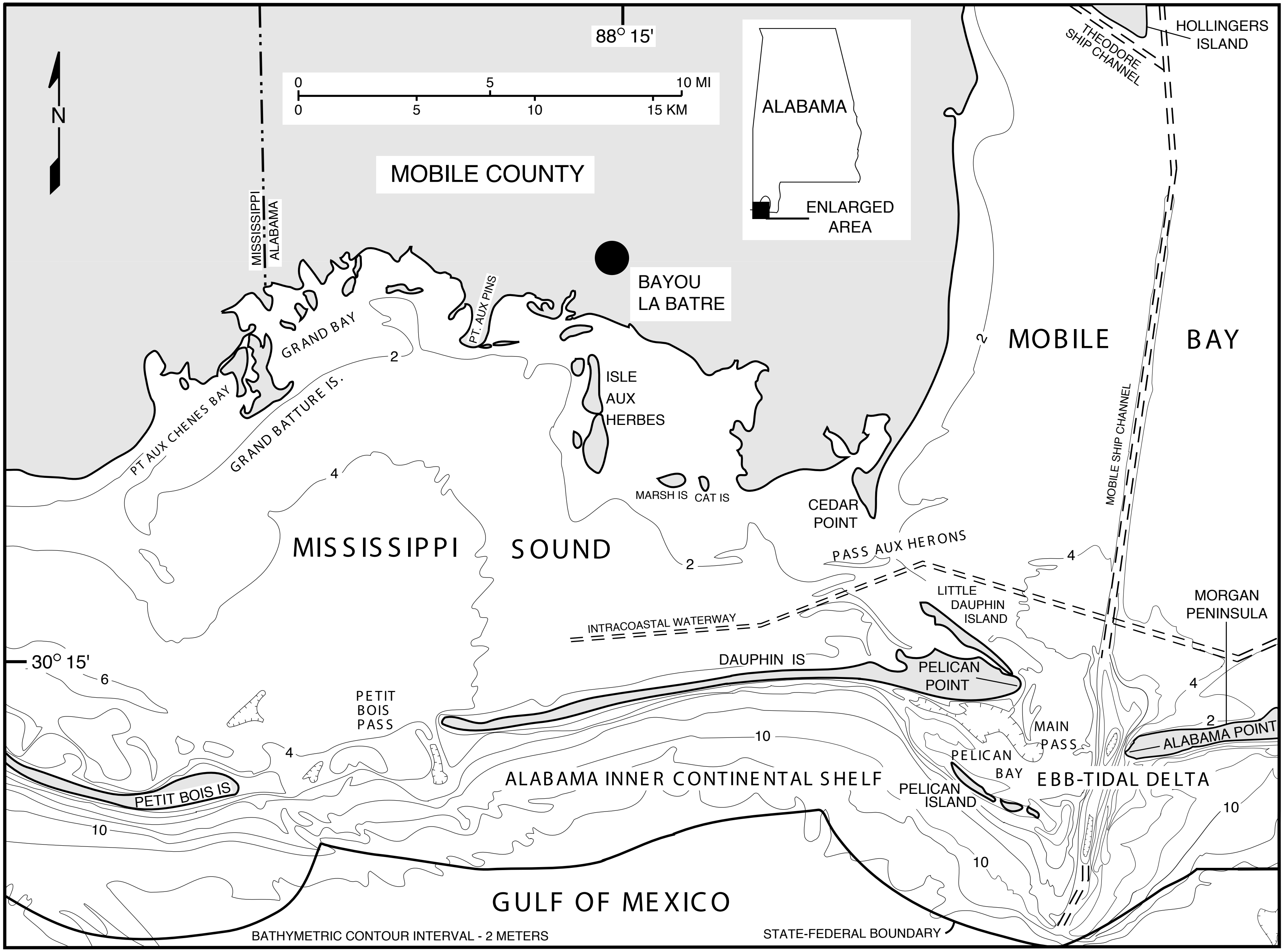


Figure 7.--Map of coastal Alabama showing the west Alabama inner continental shelf (modified from Hummell, 1996).

three-fourths of the Island is a spit where elevations are 5 ft or less except for coastal dunes that may reach a height of up to 10 ft above sea level. Washover and the opening of temporary inlets across the spit part of the Island occur as a result of cold air outbreaks, hurricanes, and tropical storms (Hardin and others, 1976; Nummedal and others, 1980).

Little Dauphin Island is a spit extending from the eastern tip of Dauphin Island into Mississippi Sound (fig. 7). The spit measures approximately 2.8 mi long, 0.6 mi wide at its widest point, and has an elevation of less than 5 ft above sea level. Tidal inlets, produced by high energy storm events (hurricanes and tropical storms) have subdivided the spit into a series of islands (Nummedal and others, 1980). Nautical charts show that these inlets have closed, reopened, and changed location over the past three centuries (Hardin and others, 1976; Hummell, 1990; Hummell and Smith, 1995, 1996; this report).

Main Pass is the 3 mi wide inlet connecting Mobile Bay to the Gulf of Mexico at the southern end of Mobile Bay (fig. 7). An ebb-tidal delta is located at the mouth of Mobile Bay measuring approximately 10 mi wide, and extending approximately 6 mi into the Gulf of Mexico, and has an average water depth of about 10 ft over its top. Its emergent portions consist of numerous shoals and ephemeral islands which enclose Pelican Bay. The ebb-flood tidal channel contains the Mobile Ship Channel, and the tidal channel has been scoured by ebb and flood tidal currents and dredging to depths of 54 to 58 ft (Boone, 1973) (fig. 7). The maximum channel depth is 60 ft due west of Mobile Point (U.S. Department of the Navy, 1986).

Pelican Island, and its sister, Sand Island (which does not exist today), are emergent parts of a northwest-southeast-trending intermittent bar adjacent to the Mobile Ship Channel (figs. 3, 7). This bar continuously changes shape, size, and location as a result of storm events, fair weather waves, and sediment movement within Pelican Bay. In the past, this bar has existed as one or more separate islands.

The ephemeral nature of the emergent portions of these bars has led to the use of various names for the islands on maps and in documents produced over the past 400 years. On the latest nautical chart (National Oceanic and Atmospheric Administration (NOAA), 1997), the emergent, northern part of the bar is labeled *Pelican Island*. The separate, emergent southern part of the bar is named *Sand Island*.

BATHYMETRY

The bathymetry of area 4 reflects the presence of the ebb-tidal delta of Mobile Bay (fig. 6). The surface of the inner continental shelf dips gently towards the southwest. The surface in the study area is relatively featureless except where it is disrupted by a northeast-southwest trending ridge lying on the ebb shield of the ebb-tidal delta of Mobile Bay. Water depths range from 6 ft or less in the northeast corner of area 4 to about 60 ft along its southern margin.

Area 4 bathymetry was originally described by Parker and others (1993) (fig. 6) and was adopted by Hummell and Smith (1995, 1996). The bathymetric data used to prepare the bathymetric map were derived from NOAA nautical charts 11373, 11376, and 11382 (NOAA, 1991a, 1991b, 1991c). Soundings from each of these charts were plotted on a single base map and contoured at 2-ft intervals. Since the time of the aforementioned studies, a 1997 NOAA nautical chart (NOAA, 1997) is available and is included as a bathymetric map in the bathymetric and bathymetric differencing map database.

CLIMATE AND METEOROLOGY

Coastal Alabama has a humid subtropical climate (Trewartha and Horn, 1980) with an average annual temperature of 68° Fahrenheit (F) and greatest range from a high of 90°F in the summer to 20°F in winter (Vittor and Associates, 1985). Wind and wave activity is low to moderate along the Alabama coast. Prevailing winds average 8 mi per hour (mph) and are stronger and northerly in the winter and calmer and southerly during the summer (Vittor and Associates, 1985). Precipitation in the form of rain occurs throughout the year, but is concentrated during summer months due to thunderstorm and tropical storm activity. Tropical storms are capable of producing heavy rainfall with typical amounts ranging from 0.4 to 0.8 ft.

HURRICANES AND TROPICAL STORMS

The central Gulf of Mexico coast has one of the highest frequencies of hurricane landfall in the United States. From 1871 through 1980 an average of 2.2 tropical storms made landfall along every 11.5 mi stretch of the coast (Neumann and others, 1981).

A hurricane is a tropical cyclone with wind velocities of 74 mph or greater, rotating counterclockwise (in the northern hemisphere) around a low-pressure center. Tropical cyclones with wind velocities of 39-73 mph are classified as tropical storms. Tropical depressions and disturbances have lesser wind velocities.

A preliminary investigation of the hurricanes and tropical storms that have affected coastal Alabama over the past 300 years was conducted as part of the present study. This research provides information about the role of high energy events in the geographic, hydrographic, and sedimentologic history of the study area. In addition, hurricanes and tropical storms are factors that must be addressed by numerical models that simulate the hydrographic history of the study area and have a direct bearing on sand resource recovery and beach nourishment projects. Introductory information about hurricanes and tropical storms is presented here, with specific findings recorded in the **HISTORIC MAP DATABASE** section of this report.

Historic records show that 55 hurricanes and 16 tropical storms affected coastal Alabama from 1700-1997 (table 2). However, based on historic documents (Hamilton, 1897; Higginbotham, 1977; Garcia and Hegge, 1985; U.S. Army Corps of Engineers, 1967, 1981), only 22 hurricanes and one tropical storm caused more than a minimal (table 1) impact on coastal Alabama.

TIDES

The astronomical tide along coastal Alabama is diurnal, i.e., with one high and one low tide per day (U.S. Department of the Navy, 1986). During the biweekly neap tide, however, two highs and two lows occur within one day (U.S. Department of the Navy, 1986). The mean tidal range is 1.2 ft at Mobile Point (Crance, 1971), which is classified as microtidal (Hubbard and others, 1979). Mean low water during the winter months ranges from 0.5 to 1.0 ft below that during the summer months (U.S. Army Corps of Engineers, 1979).

WAVES

Wave intensity along coastal Alabama is low to moderate, with periods ranging from 3 to 8 seconds and wave height rarely over 3 ft (Upshaw and

Table 2.--Hurricanes and tropical storms affecting coastal Alabama 1711-1997 (modified from U.S. Army Corps of Engineers, 1967).

Year	Hurricane or Tropical Storm	Landfall	Principal Area Affected	Year	Hurricane or Tropical Storm	Landfall	Principal Area Affected
1711	hurricane	NA	New Orleans, LA	1894	tropical storm	Pensacola, FL	Pensacola, FL
1717	hurricane?	NA	Dauphin Island	1895	tropical storm	Bayou La Batre, AL	Bayou La Batre, AL
1722	hurricane	NA	New Orleans, LA	1900	tropical storm	Port Eads, LA	Port Eads, LA
1732	hurricane	NA	Mobile, AL	1901	tropical storm	Mobile, AL	Mobile, AL
1736	hurricane	NA	Pensacola, FL	1902	tropical storm	Mobile, AL	Mobile, AL
1740	hurricane	NA	Pensacola, FL	1904	tropical storm	Port Eads, LA	Port Eads, LA
1759	hurricane	NA	Gulf coast	1906	hurricane	Pascagoula, MS	Mobile, AL
1766	hurricane	NA	Pensacola, FL	1907	tropical storm	Gulfport, MS	Gulfport, MS
1772	hurricane	NA	Louisiana	1909	hurricane	Grand Isla, LA	New Orleans, LA
1776	hurricane	NA	New Orleans, LA	1912	hurricane	Mobile, AL	Mobile, AL
1779	hurricane	NA	New Orleans, LA	1915	hurricane	Grand Isle, LA	New Orleans, LA
1780	hurricane	NA	New Orleans, LA	1916	hurricane	Gulf Port, MS	Mobile, AL
1781	hurricane	NA	New Orleans, LA	1917	hurricane	Pensacola, FL	Pensacola, FL
1800	hurricane	NA	New Orleans, LA	1919	tropical storm	Pensacola, FL	Pensacola, FL
1811	hurricane	NA	New Orleans, LA	1922	tropical storm	Pensacola, FL	Pensacola, FL
1812	hurricane	NA	New Orleans, LA	1923	tropical storm	Biloxi, MS	Biloxi, MS
1813	hurricane	NA	Gulf coast	1926	hurricane	Perdido Beach, AL	Pensacola, FL
1819	hurricane	NA	Bay St. Louis. MS	1932	hurricane	Mobile, AL	Mobile, AL
1821	hurricane	NA	New Orleans, LA	1934	tropical storm	Mobile, AL	Mobile, AL
1822	hurricane	NA	Mobile, AL	1939	tropical storm	Mobile, AL	Mobile, AL
1831	hurricane	NA	mouth of MS River	1944	tropical storm	Biloxi, AL	Biloxi, AL
1837	hurricane	New Orleans, LA	New Orleans, LA	1947	hurricane	New Orleans, LA	Mississippi coast
1842	hurricane	NA	Gulf coast	1948	hurricane	Grand Isle, LA	Louisiana
1846	hurricane	NA	New Orleans, LA	1950	hurricane	Mobile, AL	Gulf Shores, AL
1852	hurricane	NA	Mobile, AL	1956	hurricane	Ft. Walton Bch., FL	AL and NW FL
1856	hurricane	Mobile, AL	Mobile, AL	1957	tropical storm	Grand Isle, LA	Grand Isle, LA
1860	hurricane	NA	Mobile, AL	1959	tropical storm	Pensacola, FL	Pensacola, FL
1870	hurricane	NA	Mobile, AL	1960	hurricane	Pascagoula, MS	Mississippi coast
1877	hurricane	NA	Gulf coast	1964	hurricane	Franklin, LA	Louisiana
1880	hurricane	Mobile, AL	Mobile, AL	1969	hurricane	Waveland, MS	MS and LA coasts
1882	hurricane	Mobile, AL	Mobile, AL	1972	hurricane	Panama City, FL	FL panhandle
1887	hurricane	Grand Isle, LA	Mississippi coast	1979	hurricane	Mobile, AL	Mobile, AL & FL
1888	hurricane	Lake Charles, LA	LA to Mobile, AL	1985	hurricane	Biloxi, MS	MS, AL, & FL coast
1889	hurricane	Burrwood, LA	LA to Pensacola, FL	1995	hurricane	Pensacola, FL	FL panhandle
1892	tropical storm	Port Eads, LA	Port Eads, LA	1997	hurricane	St. Andrews Bay, AL	LA, MS, & AL
1893	hurricane	Pascagoula, MS	Louisiana				

others, 1966). This is consistent with the limited flood-tidal delta development landward of the ebb-tidal delta of Mobile Bay. These fair-weather waves are important for longshore transport of sediments in the nearshore zone (Upshaw and others, 1966). Wave approach is predominantly from the southeast. Intense wave activity associated with hurricanes and other storm events help rework shelf sediments (Upshaw and others, 1966; Chermock and others, 1974).

Wave heights in the nearshore area generally are proportional to wind speeds, with wave heights at a minimum during the summer and a maximum during the winter (Chermock and others, 1974). Chermock and others (1974) state that wave heights of 12 ft occur throughout the year, but heights of 20 ft or greater have been reported in February and October only.

WATER TEMPERATURES

Surface water temperatures of Gulf of Mexico waters seaward of Dauphin Island out to approximately 12 mi offshore reflect fluctuations in air temperatures, ranging from a high of 86° F to a low of 53.6° F (Vittor and Associates, 1985). Gradual warming of surface waters throughout the spring and early summer months can lead to temperature stratification during the month of July with generally uniform water temperature profiles during October and November (Vittor and Associates, 1985). In general, water temperature conforms less to air temperature with greater distance from shore and greater depth of the water column (Vittor and Associates, 1985).

SALINITY

Overall, interactions between Mobile Bay, eastern Mississippi Sound, and the Gulf of Mexico result in dynamic and constantly changing water movement in the nearshore zone. Salinity of continental shelf waters seaward of Dauphin Island is usually highly variable due to low salinity waters discharged from Mobile Bay and eastern Mississippi Sound which are mixed with marine waters of varying salinities (Vittor and Associates, 1985).

Limited data has prevented determination of any seasonal or annual cycle in nearshore Alabama salinity distribution. In general, steep salinity gradients (e.g. 0 to 36 parts per thousand or ppt) are sometimes observed within a short distance (Vittor and Associates, 1985). Meteorological events (storms and cold air outbreaks) disrupt seasonal patterns of salinity distribution. During late spring and early summer, low salinity surface water may spread over much of the nearshore continental shelf (Vittor and Associates, 1985).

HYDROGRAPHIC SETTING

GENERAL HYDROGRAPHY

Numerous small to medium spatial scale and/or short time period studies have been conducted on circulation patterns within coastal Alabama, especially Mobile Bay, employing direct measurement and remote sensing techniques. Circulation on the continental shelf of the northern Gulf of Mexico is strongly influenced by four factors: open Gulf circulation (e.g., the Loop Current), winds, tides, and freshwater discharge from rivers (Vittor and Associates, 1985). Secondary factors include the configuration of the coast, bathymetry, and the Coriolis Force.

Sustained winds tend to be the dominant driving force of the circulation on the inner continental shelf (Vittor and Associates, 1985). In the case of an onshore wind in shallow water, the surface waters will tend to flow with the wind direction while the bottom waters tend to flow offshore following a seaward-directed pressure gradient induced by an elevation of the water level near the coast (Vittor and Associates, 1985). The presence of other forces, such as a horizontal density gradient, will alter this scheme dramatically (Vittor and Associates, 1985). If a horizontal density gradient is present in the bottom waters, such that the lighter water lies near the coastline, the density current will oppose and perhaps reverse the effect of an onshore wind on the current field (Vittor and Associates, 1985). Similarly, offshore winds will drive light (and/or low salinity) surface waters away from the coast, resulting in the upwelling of heavier bottom water (Vittor and Associates, 1985). The horizontal density gradient which results is confined to the surface layer and directed offshore as a density current (Vittor and Associates, 1985).

Due to their complexity and seasonal variability, currents on the inner continental shelf are not well described (Vittor and Associates, 1985). However, general understanding of the overall patterns can be derived from the works of Schroeder (1976), Chuang and others (1982), Kjerfve (1983), and Kjerfve and Sneed (1984).

Drift bottles released during late spring and early summer from a Stage I platform located 12.4 mi offshore from Panama City, Florida, were found primarily along the northwest Florida beaches (Tolbert and Salsman, 1964). However, the recovery zone shifted westward toward Alabama and Mississippi coasts during late summer and early fall, coinciding with the peak frequency in the westward-flowing wind component (Tolbert and Salsman, 1964).

After removal of the tidal current, the influence of wind and horizontal density gradients are of great importance to current structure on the shelf. A strong onshore wind (i.e., from the southeast) results in a transient two-layer flow in the cross-shelf direction (i.e., vertical circulation patterns with onshore flow in the surface waters and offshore flow in the bottom waters) (Vittor and Associates, 1985). Subsequent to this onshore wind, strong south to southwesterly setting currents persist, establishing a relatively stable flow pattern (Vittor and Associates, 1985).

The shoreline variation in coastal geometry plays a major role in controlling circulation patterns on the shelf (Murray, 1976; Chuang and others, 1982). Variations in frequency response indicate that circulation is strongly affected by the wind duration, density stratification, and coastal geometry (Chuang and others, 1982). In his studies of the influence of wind on shelf circulation, Schroeder (1976, 1977) shows a very close correlation of bottom flow with the Ekman spiral.

Sustained winds tend to be the dominant driving force of the circulation on the inner continental shelf (Vittor and Associates, 1985). Wind-driven circulation is caused by frictional drag of the air as it passes over the surface of the water (Vittor and Associates, 1985). In deep water far from coasts, surface currents in the Northern Hemisphere are deflected 45° to the right of the wind direction; this deflection continues to rotate clockwise as depth increases, forming the logarithmic Ekman spiral (Vittor and Associates, 1985). In shallow waters far from coasts, the same balance of forces produce a deflection to the right, but the angle between wind and surface current is less than 45° (Vittor and Associates, 1985). In water depths of 5 to 10 meters (m) the maximum deflection with depth is 5 to 10° (Vittor and Associates, 1985).

Analysis of current data collected 16.1 mi south of Mobile Bay shows the tendency of near-bottom waters to be transported about 90° to the right of sustained wind direction. During July 1976, prevailing winds were to the north and northeast with near-bottom currents to the east and southeast. During November 1976, prevailing winds were to the south with a prevailing near-bottom current direction to the west. Poor correlation between wind and near-bottom current was also noted, which may occur when winds are not of consistent direction or duration to produce a sustained current direction, or when Ekman transport of bottom waters is directed toward a barrier (i.e., shoals or barrier island). This may occur in the study area when northeast, east, or southeast winds tend to move bottom waters shoreward. This shoreward movement is hindered by barrier islands and thus the bottom water will be turned and will flow along the isobaths.

The vertical structure and overall current pattern along the nearshore area of Mississippi Sound and Alabama is considered a two-season event with transitional periods (Kjerfve and Sneed, 1984). Winter, with frequent energetic storms and low freshwater imput, is characterized by a well-mixed water column. The regional winter current pattern is dominated by longshore currents flowing to the west in response to the strong offshore-directed mean winds (Schroeder and others, 1985) (fig. 8). In spring, increased freshwater runoff, coupled with a reduction in mixing energy as a result of fewer and less intense storms, results in the development of a partially stratified water column. Once initiated, stratification is maintained through the summer by solar heating of the surface waters and a further reduction of storm-derived mixing. With the reversal and reduction in strength of the prevailing winds to onshore conditions,

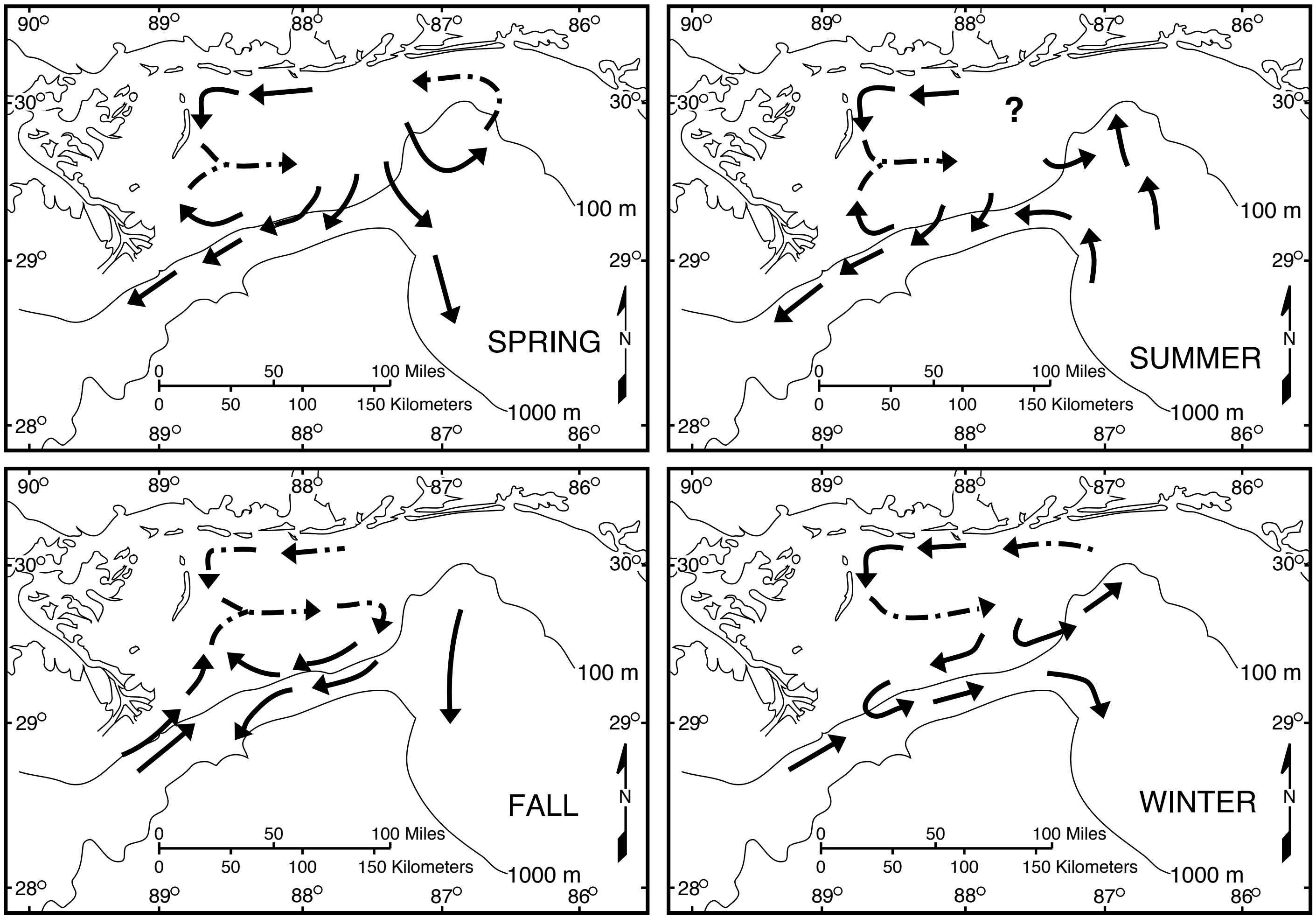


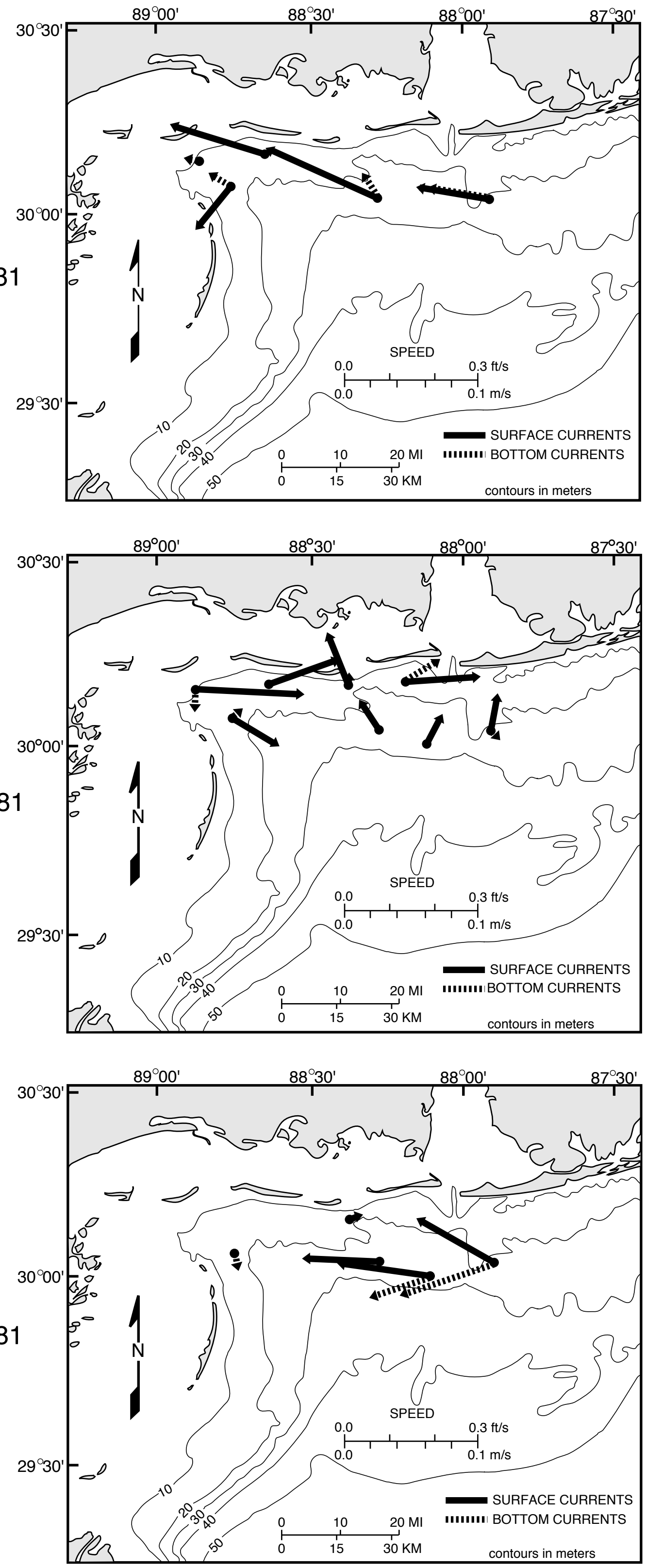
Figure 8.--Circulation patterns on the east Louisiana-Mississippi-Alabama continental shelf (modified from Parker, 1990).

the regional circulation can reverse to exhibit longshore movement towards the east (Schroeder and others, 1987) (fig. 8). Peak current speeds for either flow direction exceed 1 ft per second (fps) (Dinnell, 1988).

Kjerfve and Sneed (1984) further document the seasonal differences in oceanographic conditions in the study area during a one-year investigation (1980-81) offshore of coastal Mississippi and Alabama, based on three 45-day deployment periods at eight current meter stations (surface and bottom) (fig. 9). The mean currents for each of the three current meter deployments, indicated in figure 9 as mean vectors, have different overall current characteristics. During the November 1980 to January 1981 deployment (A), mean surface flow was towards the west with bottom currents flowing north and west away from the barrier islands. During the March through May 1981 deployment (B), surface currents were largely to the east with bottom currents to the north at six of the eight stations. During the July through September 1981 deployment (C), both surface and bottom currents were largely directed towards the west.

Although tidal currents are considered the most energetic currents observed on the shallow shelf, Kjerfve and Sneed (1984) concur that nontidal wind-induced circulation is the principal driving force of low frequency circulation. In an attempt to generalize predictions of surface and bottom flow directions based on meteorological and current data of Schroeder (1976, 1977), TerEco (1979) constructed probable current regimes on the shallow Mississippi-Alabama shelf during specified sustained wind conditions. The circulation patterns as shown do not take into account open Gulf of Mexico influence, density currents, or storm conditions.

With sustained winds from the west, northwest, north, or northeast, the estimated average near-bottom current speed as measured at Anderson Reef in 20-m water depths is 20 centimeters per second (cps) and the maximum



NOV. 1, 1980 - JAN. 9, 1981

MAR. 21 - MAY 23, 1981

JUL. 18 - SEPT. 16, 1981

Figure 9.--Mean current velocities on the East Louisiana-Mississippi-Alabama inner continental shelf (modified from Parker, 1990).

sustained hourly speed is 46 cps (TerEco, 1979). During northeast winds there is a tendency for bottom water to move shoreward; however, bottom topography causes this portion of the flow to turn westerly along the shelf.

When winds are sustained from the southeast, south, southwest, or west, the estimated average near-bottom current speed is 26 cps and the maximum sustained hourly speed is 60 cps. During periods of sustained southeast winds, bottom water tends to move shoreward; however, bottom topography probably causes that portion of the flow to turn eastward.

Sustained winds from the northeast, east, or southeast yield an estimated average near-bottom current speed of 26 cps and a maximum sustained hourly speed of 60 cps. Under these wind conditions there may be a tendency for bottom and surface waters to flow shoreward, resulting in an accumulation of water along the coast. The accumulated water will generally inhibit further shoreward movement and may result in bottom transport parallel to shore in the direction of the wind. If winds are sufficiently strong, this accumulated water along the coast may force bottom water away from shore.

DIRECT MEASUREMENT

Seim and others (1987) collected hourly water level and current data from Mississippi Sound, Mobile Bay, and adjacent Gulf of Mexico for the period April 1980 to October 1981. The current data was obtained from 29 stations and the data is summarized in figure 10. In the figure, the arrow length gives the mean surface major axis current amplitude and arrow orientation gives the direction at maximum flood tide. Gulf of Mexico flood tide surface waters flow in a generally northern direction at speeds of several centimeters per second, accelerating to reach tens of centimeters per second where water flow is channelized in inlets.

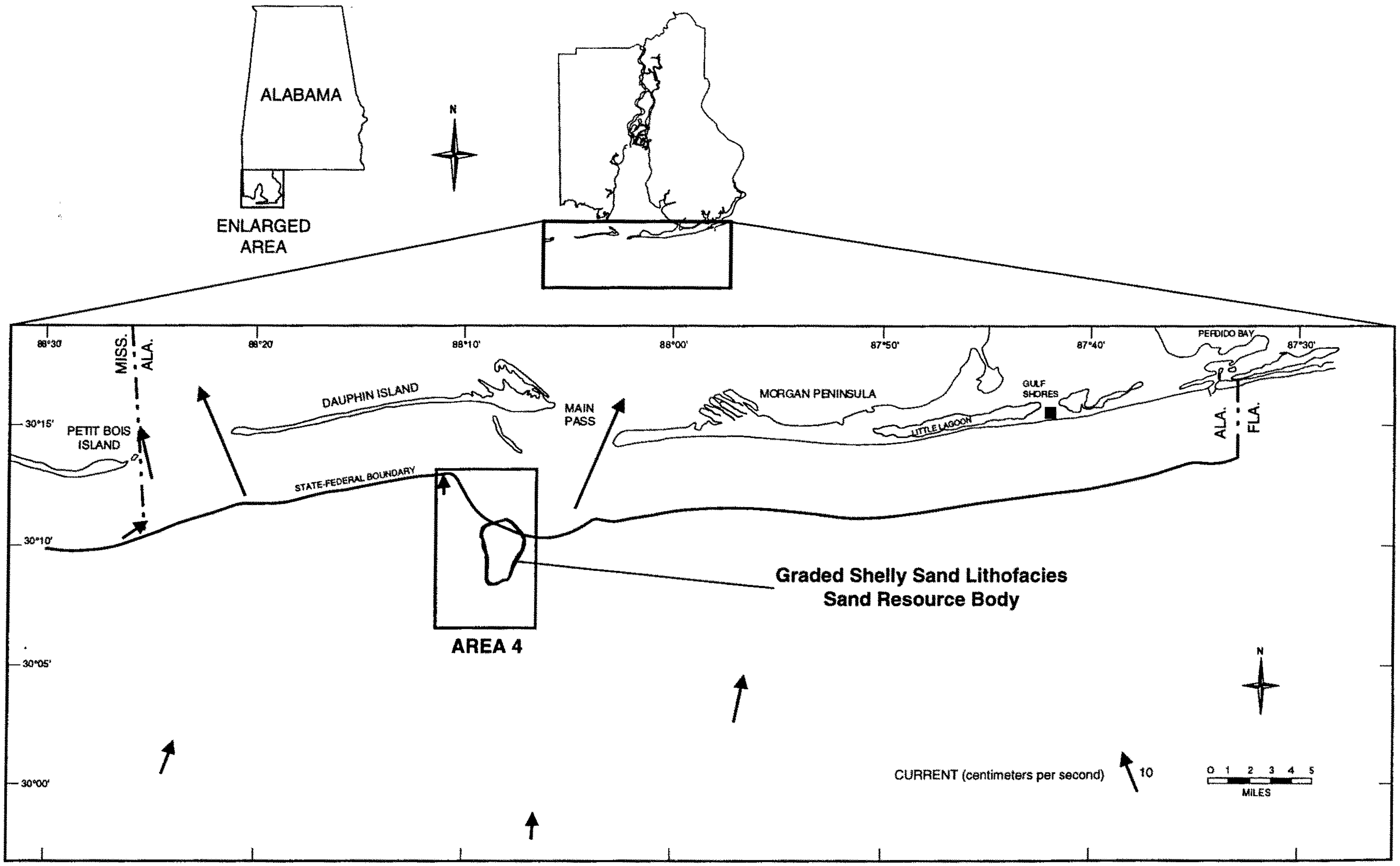


Figure 10.--Index map of the Alabama inner continental shelf showing site of the Graded Shelly Sand Lithofacies sand resource body and currents. Arrow length represents surface major current amplitude and orientation gives direction at maximum flood tide (modified from Seim and others, 1987).

Flood tide surface currents in the sand resource site are estimated to average north-northeast at 8 cps.

The low frequency current variability on the Alabama continental shelf was examined by Chuang and others (1982) from three years (1976, 1978, and 1979) of summer current, sea level, and meteorological records. The current meter mooring was located about 16.1 mi south of the east end of Dauphin Island in about 25 m of water. The latitude-longitude coordinates place the mooring about 6 mi south of area 4. The current meter was set at a 1-hour sampling interval and placed 5 m above the sea bottom. Cross-shelf currents (northward) averaged about 2 cps for the three year period with the strongest currents only about 5 cps. Longshore currents (westward) averaged about 5 cps for the same time period with the strongest currents about 15 cps.

SATELLITE AND AERIAL PHOTOGRAPHY

Remotely-sensed suspended sediment data in coastal regions is a useful tracer for studies of estuarine circulation and estuarine-shelf exchange. However, very few of these studies have addressed Alabama inner continental shelf circulation using remote sensing. Satellite imagery has been used to describe estuarine-shelf response to cold-air outbreaks (Schroeder and others, 1985) and Mobile Bay discharge sediment plume morphology (Abston and others, 1987; Stumpf and Pennock, 1989; Stumpf and Gelfenbaum, 1990). Regional estuarine-shelf exchange is important to an understanding of the general physical circulation and, consequently, transport of suspended sediment (Schroeder and Wiseman, 1986; Wiseman, 1986; Abston and others, 1987; Wiseman and others, 1988).

Abston and others (1987) used Landsat imagery for the years 1973 to 1983 to provide scenes of Mobile Bay sediment plume morphology that can be correlated with coastal processes occurring at the time of the image. Mobile Bay sediment plumes introduce a significant amount of suspended sediment to the inner continental shelf of Alabama and Mississippi. The plumes may extend along the inner continental shelf 22 mi east and west of Main Pass and offshore as far as 30 mi (Abston and others, 1987). Reworking of sediment as a result of normal wave activity is limited to the very nearshore area. Transport of sediment from Mobile Bay onto and across the shelf, under normal conditions, is due primarily to tidal flushing and longshore currents. Wind wave resuspension of both estuarine and shallow shelf sediments occurs during cold-air outbreaks, from November through April (Schroeder and others, 1985). Hurricanes and tropical storms, with higher wave activity, are important factors in the reworking of shelf sediments.

They defined four morphological types of Mobile Bay sediment plumes. Measurable parameters of plume morphology are area, length, width, and orientation which were correlated with environmental forcing parameters (river discharge, the time elapsed since the last high tide, predicted tidal range, and wind speed and direction). An increase in plume area is generally correlated with higher river discharge. Daily tides initially flush turbid water from Mobile Bay onto the shelf. Although the tidal range, to a large extent, determines the volume of water introduced to the shelf, the plume area determined by imagery appears influenced more by the time since the last high tide. Once the plume is on the shelf, its orientation and dispersal pattern is influenced by surface currents and local wind. Plume orientation seems dependent on longshore current direction. Deflection of plumes is usually westward, corresponding to the mean westward flow of the inner shelf, but sufficient eastward winds may reverse the inner shelf currents and deflect plumes eastward. Plume size is also affected by an Ekman transport that is related to longshore wind directions. Water is forced offshore as winds blow to the east; winds to the west force water toward shore. Plumes are dispersed and carried seaward as winds blow to the east and are confined to the inner shelf area as winds blow to the west. Generally, high values of river discharge, tidal range, and time since the last high tide, along with winds to the east or southeast, produces the most favorable conditions for the development of large plumes.

Dinnel and others (1990) quantified the relationships between Mobile Bay sediment plume morphology and environmental forcing parameters discussed by Abston and others (1987). Dinnel and others (1990) used correlation and regression analyses to determine statistical relationships between plume morphology and environmental forcing. They found that plume morphology, defined by area, length, and width, are primarily related to river discharge with modulating effects due to the tides. Up to a certain level of river discharge, 4,500 cubic meters per second, plume size is directly related to tide phase, i.e. the longer the tide has ebbed, the larger the plume. Above this level the river discharge dominates the plume size. Yet, even at times of large river discharge, the tidal range and phase modifies the plume size.

Local winds, either across or longshore, do not seem to be significantly related to plume size. Yet, the longshore winds are well correlated with the orientation of the discharge plume. The direction of the longshore currents is related to the wind direction, so the orientation of the discharge plumes are thought to be a result of advection by the local current, an indirect result of the longshore winds, as well as a result of direct momentum transfer from the wind.

Geographic variation in sea bottom sediment type in area 4 is subject to prevailing hydrographic and oceanographic conditions (many of which show distinct seasonal variation), which constantly rework and redistribute surficial sediments. Heterogeneity of nearshore sediments is attributed to Holocene transgression, variation in local bathymetry, changes in sediment transport pathways, reworking by wave activity, and sedimentation associated with sediment plumes emanating from

Mobile Bay (Swift and others, 1971; Pyle and others, 1975; Chuang and others, 1982; Abston and others, 1987; Wiseman and others, 1988). Tidal inflow and outflow through Main Pass redistributes estuarine sediments in the southern half of Mobile Bay and transports fines out of Mobile Bay. Most of the sediment exiting Mobile Bay is deposited south to west of Main Pass, in response to the predominant westward directed littoral drift, forming an ebb-tidal delta (U.S. Army Corps of Engineers, 1979). During summer months, some of the fines move eastward in response to an eastward component of the longshore drift (U.S. Army Corps of Engineers, 1979). Deposition of sand from ebb-tidal sediment plumes occurs seaward of Main Pass on the ebb ramp, with clays and silts being deposited on the shelf seaward of the ebb shield which includes area 4 (fig. 3).

Area 4 experienced two meteorological and climatological events in 1997 that have affected the sand resource body in area 4. State-wide in 1997, Alabama received the highest spring rainfalls since 1900 (S. Mettee, 1997, oral communication). The MMS's, two-year environmental and ecological assessment study has encountered widespread fine-grained sediments blanketing the sea floor in areas 4 and 5 during a May 1997 biological sampling cruise (R. Hammer, 1997, oral communication). The sediments are likely to represent material deposited from Mobile Bay sediment plumes that were generated by spring high freshwater discharge events of the Mobile-Tensaw River system. The fine-grained sediment texture, sheet geometry of the deposit, locations of areas 4 and 5 in plume pathways, and proximity to Petit Bois and Main Passes where plumes emanate, are evidence to support plumes. An October 1997 sea floor biological sampling cruise by the environmental and ecological assessment study team will gather further information on the plume deposits.

Hurricane Danny struck the Alabama coast on July 18, 1997. Its impact on areas 4 and 5 is unknown. It is possible that the plume deposits were removed by storm wave and current activity, or additional plume deposits were laid down in the areas by high freshwater discharge events associated with storm rainfall. The October 1997 biological sampling cruise may provide information on the effects of Hurricane Danny on the sand resource body.

SEDIMENT TRANSPORT

Along the seaward sides of Dauphin Island and Morgan Peninsula, longshore currents have the most apparent affect on the transport of sediment (Parker, 1990). Longshore currents typically move east to west at rates of 1.6 to 4.4 fps and on incoming tides may increase to 4.4 to 8.8 fps (Foxworth and others, 1962). Sustained northwestern or western winds may cause temporary reversals in the longshore current direction. On the average, 3-day sustained eastward winds are required to reverse the longshore current direction (Abston and others, 1987).

Wind, waves, tides, and currents are the dominant factors controlling water movement within the study area. As a result, these factors are important in sediment transport. In the estuarine systems, tides are the major influence on circulation and sediment transport. Ebb tides disperse tons of fine-grained, suspended sediment through the tidal passes and onto the adjacent shelf. Much of this material is deposited directly southwest of the tidal passes in elongate lenses due to longshore currents. Flood tides, which generally produce weaker currents than ebb tides, inhibit transport of sediment from the estuaries to the shelf. Sustained southerly or southeasterly winds suppress ebb tides while enhancing flood tides, which decreases the transport of suspended sediment load to the shelf. Conversely, northerly winds and high river discharge increase ebb tidal flow and elevate the amount of suspended sediment being transported to the shelf. Within the narrow tidal inlet passes, tidal currents are elevated and fine-grained sediment is winnowed out. As a result, fine- to medium-grained sand occurs in Petit Bois Pass, Main Pass, and Perdido Pass. The amount of bedload coming out of the bays is difficult to quantify; thus, data concerning volume of bedload are not available. Transport of bedload from Mobile Bay is evidenced by a large ebb-tidal delta occurring south of Main Pass.

Tides have little affect on sediment movement on the shelf; however, they may influence sedimentation as they accelerate crossing the shelf (Upshaw and others, 1966). Longshore currents transport sediment along the seaward coasts of the barrier islands. Wave and current activity is primarily responsible for sedimentation on the shelf. Under normal conditions in the study area, waves and currents can move fine- to medium-grained sand in water depths of 20 m; however, little or no net horizontal displacement occurs (Dinnell, 1988). Hurricanes produce waves and currents strong enough to disturb sediments on the outer shelf. Near the shelf edge, sediments are disturbed about once every 5 years (Upshaw and others, 1966).

The amount of sediment entrained in the littoral system along the Mississippi-Alabama barrier islands is not known with confidence. However, Garcia (1977) determined that the total net littoral transport at Dauphin Island to be about 196,000 cubic yards (yd^3) per year. This agrees well with the U. S. Army Corps of Engineers (1955) estimate of 200,105 yd^3 per year at Perdido Pass and 212,111 yd^3 per year estimate for Petit Bosis Island (U.S. Army Corps of Engineers, 1984).

1.

STUDY AREA SURFACE SEDIMENTS

GRAIN SIZE

The Mobile-Tensaw River system drains approximately 34,600 square miles (mi^2) in the states of Alabama, Georgia, and Mississippi (Mettee and others, 1989). These areas include terrains of the Appalachian Valley and Ridge, Plateau, Piedmont, and Gulf Coastal Plain (fig. 11). The entrained sediments of this stream system, therefore, have been derived from sedimentary, igneous, and metamorphic lithologies.

The Valley and Ridge and Plateau areas include sequences of Paleozoic clastic sediments, such as sandstone, shale, conglomerate and carbonate rocks, which are in part chert-bearing. Lithologies of the Piedmont area include granite and granite gneiss, quartzite, schist and other metamorphic lithologies. Coastal plain areas include sediments derived primarily from the Valley and Ridge and igneous and metamorphic areas.

The major lithologic contributions to fluvial deposits, and ultimately to Gulf sized sediments from the above described areas, include gravel, sand, silt and clay-sized quartz, quartzite, and chert. In addition, many accessory minerals, such as zircon, rutile, tourmaline, kyanite, ilmenite, monazite, garnet, hornblende, and others, are derived from these areas and ultimately become minor constituents of Gulf sediments. The Coastal Plain area consists of poorly consolidated sedimentary rocks which are derived, in part, from the Valley and

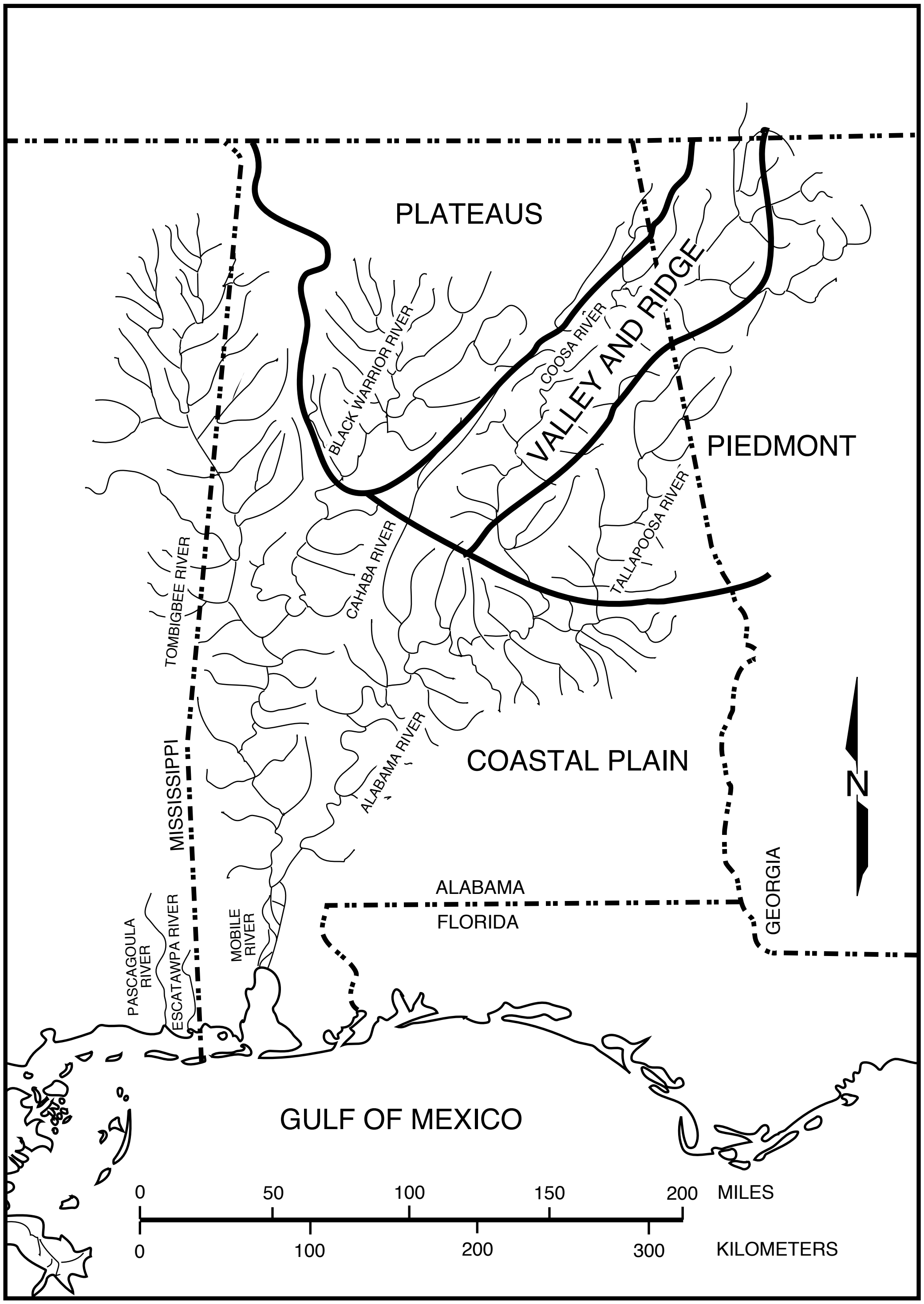


Figure 11.--Mobile River drainage basin (modified from Hardin and others, 1976).

Ridge and Piedmont terrains. Erosion of this area contributes sand, clay, gravel, and detrital heavy minerals to the fluvial deposits. Mobile Bay and eastern Mississippi Sound are filled with sediments consisting of fluvial, marine, estuarine, and deltaic clay, silt, sand, and gravel.

The Mississippi-Alabama shelf is part of a triangular-shaped region that includes parts of offshore Louisiana, Mississippi, Alabama, and westernmost Florida (fig. 5). Ludwick (1964) divided the Mississippi-Alabama shelf into six facies (fig. 5). The study area lies in the nearshore fine-grained facies which is comprised of sand, muddy sand, sandy mud, and mud (fig. 5). These sediments are deposited at water depths generally less than 60 ft and in a zone about 7 mi wide.

Published granulometric data from bottom samples collected within the study area are widely scattered in the literature, differ widely in collection dates, are site specific, differ widely in the nature of the project, methods used and the form of presentation of the data in a report, and are largely qualitative. The most recent surface sediment texture map is from 1984 (U.S. Army Corps of Engineers, 1984) (fig. 12). Parker and others (1993) constructed a surface sediment texture map for the Alabama EEZ utilizing the U.S. Army Corps of Engineers (1984) map and data from several sources. Granulometric analysis of bottom samples collected from area 4 by Hummell and Smith (1995, 1996) and nearshore Alabama Gulf of Mexico by Hummell (1996) indicates that the U.S. Army Corps of Engineers (1984) map better reflects surface sediment texture of the study area.

Sediment types displayed on the U.S. Army Corps of Engineers (1984) sea bottom sediment distribution map for the Alabama inner continental shelf (fig. 12) occur in an approximately east-west belt of sand encompassing Dauphin and Little Dauphin Islands, Main Pass, and Morgan Peninsula. This belt occurs

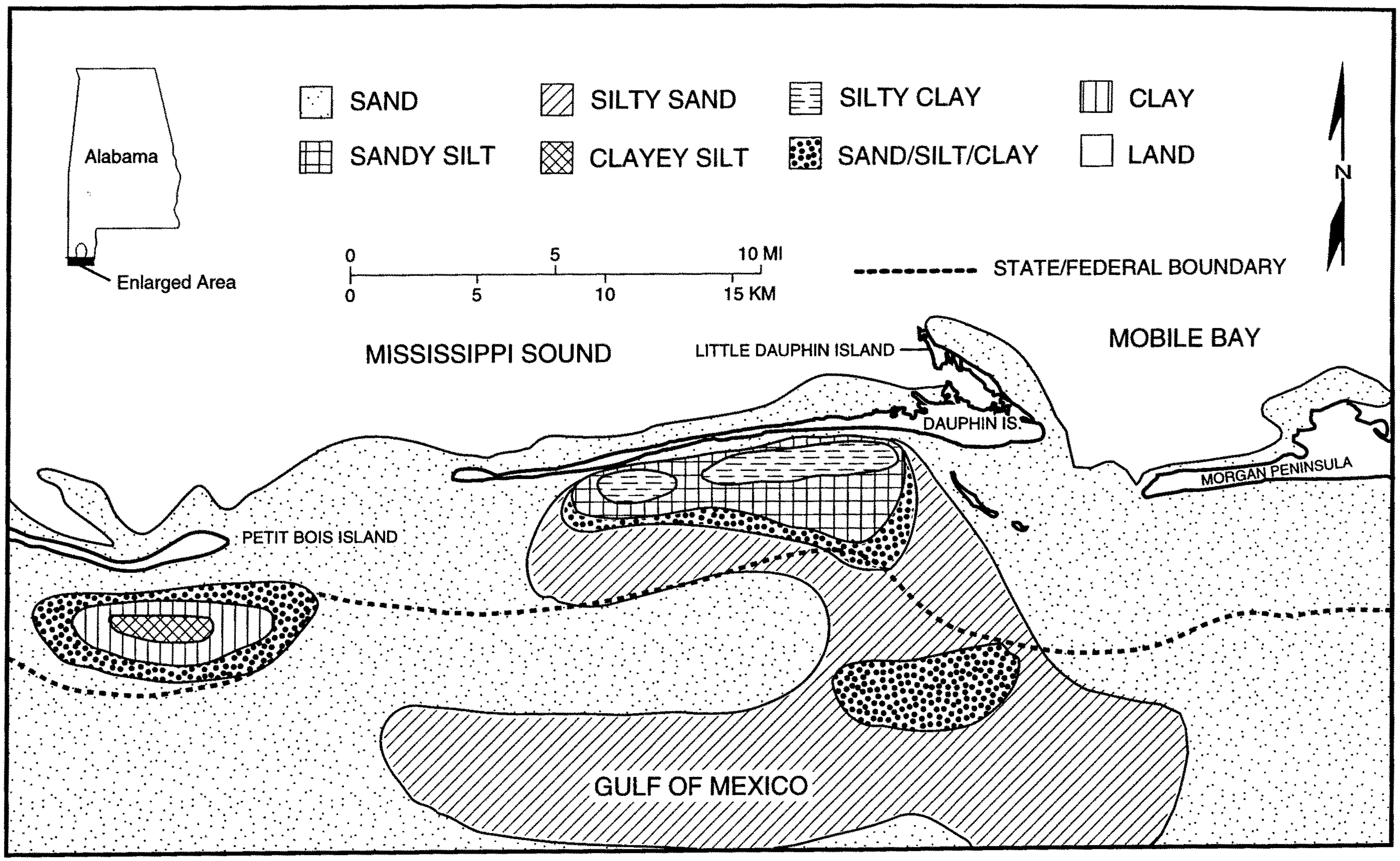


Figure 12.--Sediment distribution in the west Alabama inner continental shelf (modified from U.S. Army Corps of Engineers, 1984).

between the Mobile Bay clays and silts and the ebb-tidal delta clays and silts. Narrow, east-west oriented zones of silty clay lie just south of Dauphin Island. Area 4 surface sediments consist of mostly silty sand with a patch of sand/silt/clay in the central portion of the study area. Sand covers the sea bottom surface in the northeastern portion of area 4.

Geographic variation in sea bottom sediment type is subject to prevailing hydrographic and oceanographic conditions (many of which show distinct seasonal variation), which on the Alabama inner continental shelf constantly rework and redistribute surficial sediments. Heterogeneity of nearshore sediments is attributed to Holocene transgression, variation in local bathymetry, changes in sediment transport pathways, reworking by wave activity, and sedimentation associated with sediment plumes emanating from Mobile Bay (Swift and others, 1971; Pyle and others, 1975). Tidal inflow and outflow through Main Pass redistributes estuarine sediments in the southern half of Mobile Bay and transports fines out of Mobile Bay. Most of the sediment exiting Mobile Bay is deposited south to west of the Main Pass, in response to the predominant westward directed littoral drift, forming an ebb-tidal delta (U.S. Army Corps of Engineers, 1979). During summer months, some of the sediment fines move eastward in response to an eastward component of the littoral drift (U.S. Army Corps of Engineers, 1979).

Average sea bottom sediment grain size gradually decreases both landward and seaward of the strandline. Deposition of sand from ebb-tidal sediment plumes occurs seaward of the tidal inlet on the ebb ramp, with clays and silts being deposited on the shelf seaward of the ebb shield (figs. 3, 12). Flood-tidal currents carry shelf sands landward of the strandline, and these mix with clays and silts in southern Mobile Bay. This sea bottom sediment distribution is similar to that of the ebb-tidal delta of North Edisto Inlet, South Carolina, which was described by Imperato and others (1988).

HEAVY MINERALS

Foxworth and others (1962) studied the heavy mineral assemblage of the Mississippi-Alabama barrier islands and found that island sediments contained a tourmaline-kyanite suite of heavy minerals. This suite falls in the eastern Gulf of Mexico heavy mineral province which is characterized by a relatively high content of ilmenite, staurolite, kyanite, zircon, tourmaline, and stillimanite, and by low percentages of magnetitie, amphiboles, and pyroxenes (Hsu, 1960; Van Andel and Poole, 1960; Doyle and Sparks, 1980). The barrier island sands are thought to have been derived from erosion of pre-Holocene coastal plain sediments and reworking of Pleistocene inner continental shelf alluvial deposits (Rucker and Snowden, 1989). Concentrations of heavy minerals occur as thin laminae to medium beds in back barrier beaches and coastal eolian dunes. Foxworth and others (1962) proposed that longshore currents, waves, and tides move heavy minerals onshore, while storm waves, winds, and rain runoff concentrate these minerals into layers.

Upshaw and others (1966) found concentrations of heavy minerals greater than 4 percent in Petit Bois Pass surficial sediments. Studies by Stow and others (1975), Drummond and Stow (1979), and Woolsey (1984), found heavy mineral concentrations of up to 2.4 percent in surficial shoreface sediments off the west end of Dauphin Island and in Pelican Bay. Stow and others (1975) suggested that these shore-parallel elongated heavy mineral concentrations are a result of a combination of longshore transport and wave action. The ultimate source of heavy minerals for Dauphin Island and nearshore Alabama inner continental shelf sediments is the igneous-metamorphic complex of the southern Appalachian Mountains.

CLAY MINERALS AND CARBONATE

On the shelf, smectite and kaolinite are the predominant clay minerals, with illite present in smaller quantities (Doyle and Sparks, 1980). Smectite, which is characteristic of the Mississippi River and Mobile-Tensaw River systems, is predominant on the continental shelf. Smectite increases while kaolinite decreases offshore over most of the continental shelf south of the study area (Doyle and Sparks, 1980).

Surficial shelf sediments are comprised mostly of sand to clay-sized terrigenous quartz with less than 25 percent carbonates (Vittor and Associates, 1985). Ryan and Goodell (1972) found that carbonate percentages were due to the presence of whole and disarticulated bivalve shells and that most of the gravel-sized clasts were composed of shell debris. Carbonate content increases southwest of Main Pass (Ryan and Goodell, 1972).

HISTORIC MAP DATABASE

INTRODUCTION

Bathymetric and bathymetric differencing maps dating from 1732 to 1997 interpreted with knowledge about historic hurricanes that have impacted coastal Alabama, U.S. Army Corps of Engineers Mobile Ship Channel dredge records, historic documents and eyewitness accounts, and sea floor sediment texture maps lead to an improved understanding of the sediment transport system. This understanding can be used, in part, to verify and refine numerical models of water circulation and sediment transport in area 4 and along the southeastern Dauphin Island shoreline. In addition, the database of maps provides case studies that can be used to test the validity of the numerical model and improve the ability of the model to approximate system behavior. This portion of the study completed task 2 of the project.

PREVIOUS INVESTIGATIONS

Ryan (1969) utilized soundings on unpublished hydrographic survey sheets of the U.S. Coast and Geodetic Survey to produce Mobile Bay bathymetric maps for the time intervals 1847-51 and 1960-62. He produced a depth change (bathymetric differencing) map by superimposing the two maps and calculating the depth difference between the two maps. The bathymetric differencing map shows net change in Mobile Bay sedimentation (erosion, no change, or accretion) between 1847-51 and 1960-62. Ryan (1969) analyzed the bathymetric and bathymetric differencing maps, a sea floor sediment texture map, clay mineral distribution of sea floor sediments, and the historic distribution of oyster beds for Mobile Bay. He found that the circulation patterns within Mobile Bay are controlled primarily by the Mobile-Tensaw River system discharge, tides, and the geometry of the Bay, with short term variations in Bay circulation due to meteorological tides. Mobile Bay circulation can be classified as highly stratified, moderately stratified, or vertically homogenous depending on seasonal and annual climatic variations (Ryan, 1969). Ryan (1969) calculated a Bay-wide average sedimentation rate of 1.7 ft per century for the period 1847-51 to 1960-62. He concluded that Mobile Bay is slowly infilling, based on the net sediment fill for Mobile Bay between 1847-51 and 1960-62. Anomalous local sedimentation rates are attributed to changes in circulation and bathymetry due to ship channel dredging (Ryan, 1969). The geographic distribution of sea floor bottom sediment texture and clay mineral species reflect sediment transport pathways from the head of Mobile Bay down the Bay in a generally southeast direction to Bon Secour Bay (Ryan, 1969). Ryan (1969) found that the distribution and age of Mobile Bay oyster beds indicate a gradual migration of oysters down the Bay due to progradation of Mobile Bay's bay-head delta, and changes in Bay water circulation over the past several thousand years.

Hardin and others (1976) assessed the historic shoreline of coastal Alabama and bathymetric change of Mobile Bay and nearshore Alabama Gulf of Mexico using historic hydrographic and topographic surveys, and available aerial photographs and satellite imagery. Bathymetric maps for the years 1852, 1920, and 1973 were generated from soundings data using the Harvard University computer program SYMAP. The study produced a series of computer generated bathymetric differencing maps covering all permutations of time intervals using the 1852, 1920, and 1973 bathymetric soundings data layers. Hardin and others (1976) drafted maps documenting coastal Alabama shoreline change during the period 1917-74 (except for the Perdido Pass area, 1867-1974). They concluded that the shorelines and nearshore sea floor of coastal Alabama are in a dynamic state, adjusting to the combined effects of natural and anthropogentic change. Shoreline segments vary in state (erosion, no change, or accretion) and rate of change geographically and over time (Hardin and others, 1976). They found that 56 percent of the 1974 coastal Alabama shoreline was eroding. Cedar Point, portions of Dauphin Island, and a portion of the northern shoreline of Morgan Peninsula are among those areas showing numerically large erosion rates in 1974 (Hardin and others, 1976). According to computations based on the 1852, 1920, and 1973 soundings data layers, Hardin and others (1976) verified Ryan's (1969) conclusion that Mobile Bay is slowly infilling with sediment. In addition, Hardin and others (1976) determined that the lower half of Mobile Bay is infilling more rapidly than the upper half.

Hummell (1990) conducted a preliminary investigation of the geoframework, and hydrographic and sediment transport systems of Main Pass and the ebb-tidal delta of Mobile Bay. He found that through man's activities and natural processes, the systems have shown significant change between 1775 and 1990. By tracking the development of the study over the past few thousand years, Hummell (1990) was able to show that the gradual sedimentation in Mobile Bay and Pelican Bay, and dredging activities in the Mobile Ship Channel, account for bathymetric changes that have occurred within the study area. These changes in bathymetry affect water circulation, which in turn, affects salinity and water temperature distributions in Mobile Bay and eastern Mississippi Sound (Hummell, 1990).

SHIP CHANNEL DREDGING AND DREDGED MATERIAL DISPOSAL

Mobile Bay has an average depth of 10 ft, and originally had a natural controlling depth of 5 ft over the bar at the mouth of the Mobile-Tensaw River system at the Port of Mobile (Bisbort, 1957). The natural controlling depth over the entrance bar to Mobile Bay at Main Pass was 23 ft (Bisbort, 1957). Over time it became necessary to dredge the Bay and Pass to accommodate ocean-going vessels (Bisbort, 1957).

The federal government began channel improvements in 1826, and through the years the channel depths and widths kept pace with the increasing size of vessels using the Port of Mobile (Bisbort, 1957). The Mobile District, U.S. Army Corps of Engineers, maintains detailed records of all dredge activities in coastal Alabama going back to the late 1860's. Unfortunately, there are no records of where the dredged material was placed. Before the establishment in the 1920's of designated dredge disposal areas, it is thought that most dredged material was dumped at the nearest available place, which in most cases, was probably on the sea floor immediately adjacent to the channel being dredged (P. Bradley, 1997, oral communication).

In some instances, there are changes in bathymetry on the bathymetric and differencing maps that can be attributed to dredging of ship channels and disposal of dredged material. These channels and sediment piles will be noted later in this report during discussion and interpretation of the individual bathymetric and bathymetric differencing maps. In addition, there are questionable dredged material piles or errors in the bathymetric data that resemble these piles. These will be pointed out as well. However, numerical modeling of the study area would be required to determine if the dredged material affected water and sediment circulation. Bisbort (1957) indicates that studies of the Mobile Ship Channel indicate that siltation of the channels, necessitating frequent dredging, is due principally to the tidal currents not coinciding with the direction of the channels. Material in suspension is deposited in the channels, because of the reduction in water velocity as sediment laden water moves over the deeper water of the channel, and encounters the levee of dredged material bordering the channel (Bisbort, 1957).

METHODOLOGY

Historic bathymetric change assessment requires the collection of all available maps that contain water depth data. In addition, the data (soundings and geography) must have been obtained by employing a level of navigational skill and technology sufficient to record the geographic position of the data accurately and precisely. To meet these two map requirements two different approaches were used to construct the map database for the present study.

The hydrographic survey maps for the northern Gulf of Mexico produced by the U.S. Coast and Geodetic Survey, beginning in 1847, meet the two requirements, and along with NOAA’s National Ocean Service nautical charts, comprise the standard database for historic bathymetric studies. For the present study, all hydrographic survey maps and nautical charts covering the study area were obtained and evaluated. Table 3 shows the final set of maps and charts that were used in the study. These maps are U.S. Coast and Geodetic Survey (1847-48; 1892; 1908; 1917-18; 1920; 1927; 1941; 1960; 1969), and NOAA (1977; 1987; 1997).

There are a vast number of pre-1847 maps available for study that show coastal Alabama. However, only four of these maps meet the two requirements and they have been included in the map database of this study (table 3). These maps are 1732 (Hamilton, 1897), 1771 (Hamilton, 1897), 1775 (Romans, 1772/73-1775), and 1822 (U.S. Department of War, 1822).

The scales of the 1847-1997 maps used in the project ranged from 1/10,000 to 1/80,000 and the pre-1847 maps were of a variety of scales (table 3). In addition, the maps were produced using several independent datums. Standard techniques were used to first rectify the maps. The rectified maps

Table 3.--Historic hydrographic maps used in this report.

Year(s)	Source	Catalogue Number	Scale
1732	Hamilton (1897)	NA	NA
1771	Hamilton (1897)	NA	NA
1775	Romans (1772/73-1775)	NA	NA
1822	U.S. Department of War (1822)	NA	NA
1847-48	U.S. Coast and Geodetic Survey	H-192	20,000
1892	U.S. Coast and Geodetic Survey	H-2124	20,000
1908	U.S. Coast and Geodetic Survey	H-2939	20,000
1917-18	U.S. Coast and Geodetic Survey	H-4023	40,000
1920	U.S. Coast and Geodetic Survey	H-4171	80,000
1927	U.S. Coast and Geodetic Survey	1266	80,000
1941	U.S. Coast and Geodetic Survey	H-6686	20,000
1960	U.S. Coast and Geodetic Survey	H-8526	10,000
1969	U.S. Coast and Geodetic Survey	1266	80,000
1977	National Oceanic and Atmospheric Administration	11376	80,000
1987	National Oceanic and Atmospheric Administration	11376	80,000
1987	National Oceanic and Atmospheric Administration	11376	80,000

were converted to a common scale of 1/80,000 and to the North American 1927 Datum.

A 0.5°-latitude by 0.5°-longitude grid was superimposed on each rectified map. The water depths at each grid intersection on each map were interpolated and recorded on a transparent overlay. The water depths on some of the maps were given in fathoms, which were converted to feet. Another transparent overlay was placed over the first overlay (containing the water depths) and the depths contoured to produce a bathymetric map. Bathymetric differencing maps were constructed by first superimposing the water depth transparencies from two chronologically consecutive dates and placing a clean transparency on top. Water depths at each grid intersection were subtracted and the bathymetric difference recorded on the top transparency. The top transparency containing the bathymetric difference data was removed and a clean transparency placed on top. The bathymetric difference data was contoured with positive values indicating net accretion and negative values indicating net erosion. The line drawings of bathymetric and bathymetric differencing maps were scanned into a computer and drafted into final figures. The average estimated error of the water depth data is 1 foot vertical distance, and up to 500 ft horizontal distance.

The pre-1847 maps contain internal unrectifiable errors (especially longitude) attributed mostly to navigation. Even though the 1775 and 1822 maps are very good for their times, the pre-1847 bathymetric maps are only accurate to the point of portraying the general placement and configuration of coastal land and bathymetry. Bathymetric differencing maps were not constructed from the pre-1847 bathymetric maps because of the level of error in sounding locations.

On the pre-1847 maps, shorelines were drawn with some hard data, some guesswork, and artistic license. Shorelines on the 1847-1997 maps were copied from the U.S. Geological Survey topographic maps of the time. The shorelines on the bathymetric maps are those that appeared on the actual maps. Bathymetric differencing maps show the shoreline of the most recent of the two map dates being compared.

BATHYMETRIC AND BATHYMETRIC DIFFERENCED MAPS

BATHYMETRIC MAPS 1732-1848

Area 4 bathymetry was originally described by Parker and others (1993) (fig. 6) and was adopted by Hummell and Smith (1995, 1996). The bathymetric data used to prepare the bathymetric map were derived from NOAA nautical charts Nos. 11373, 11376, and 11382 (NOAA, 1991a, 1991b, 1991c). Soundings from each of these charts were plotted on a single base map and contoured at 2 ft intervals.

The port of Mobile is located at the northern end of Mobile Bay. The Spanish Admiral de Pineda was the first European to discover and explore Mobile Bay in 1519 (Bisbort, 1957). He recognized the Bay's strategic position and other advantages on an exploration map sent to Spain in 1520. Other Spanish explorers followed, generating a series of nautical charts. Canadian seaman Bienville made use of the Spanish nautical charts to establish a post on the east end of Dauphin Island in 1699 (Hamilton, 1897). A permanent French colony, Fort Louis de la Louisiana, was established in 1702 by Bienville on the Mobile River at 27-Mile Bluff (near the present town of Mount Vernon) (Hamilton, 1897; Higginbotham, 1977). The shallow water of Mobile Bay prevented French supply ships from sailing up the Bay to Fort Louis (Hamilton, 1897; Higginbotham, 1977). However, at that time, a natural crescent-shaped anchorage was available at the east end of Dauphin Island (fig. 13). The anchorage was 30 to 35 ft deep, connected by a 20-ft deep pass at the western end, and was able to hold 15 to 30 ships (Hamilton, 1897). Supplies bound for Fort Louis were offloaded from ocean-going vessels at Dauphin Island. The cargo was then loaded into smaller, shallow-draft vessels which sailed up Mobile Bay to Fort Louis. Due to river flooding from a hurricane (September 11-13, 1711) and the need to reduce the travel distance between Fort Louis and Dauphin Island, the Fort was moved to the present site of Mobile in 1711 (Hamilton, 1897; Higginbotham, 1977). The port at Dauphin Island prospered until a storm in May 1717 filled the pass at the western end of the anchorage with sand, thus sealing off the harbor (fig. 14) (Bisbort, 1957). By the early 1720's, the port at Dauphin Island was abandoned (Hamilton, 1897). Ocean-going vessels now docked in Pensacola or Biloxi, where supplies destined for Fort Louis were offloaded into smaller, shallow-draft vessels which sailed to Fort Louis (Hamilton, 1897; Higginbotham, 1977).

Figure 13 indicates that Pelican Island was joined to Dauphin Island by a narrow sand bar in 1717, prior to the May 1717 storm that ultimately closed the harbor. In addition, the water west of Pelican Island was deep enough to accommodate an ocean-going vessel. Figure 14 shows the harbor in 1718. Pelican Island (labeled *Islette aux Espagnols*) was still attached to Dauphin Island.

The earliest historic map of the study area containing water depths, 1732, appears in Hamilton (1897). The 1732 bathymetry of area 4 appears fairly uniform with water depth increasing toward the south-southwest (fig. 15). Pelican Island has disappeared with Sand Island represented by three islands. Water depths along southeastern Dauphin Island appear to have decreased from 21 ft in the early 1700's (Hamilton, 1897) to 5-10 ft in 1732. Two

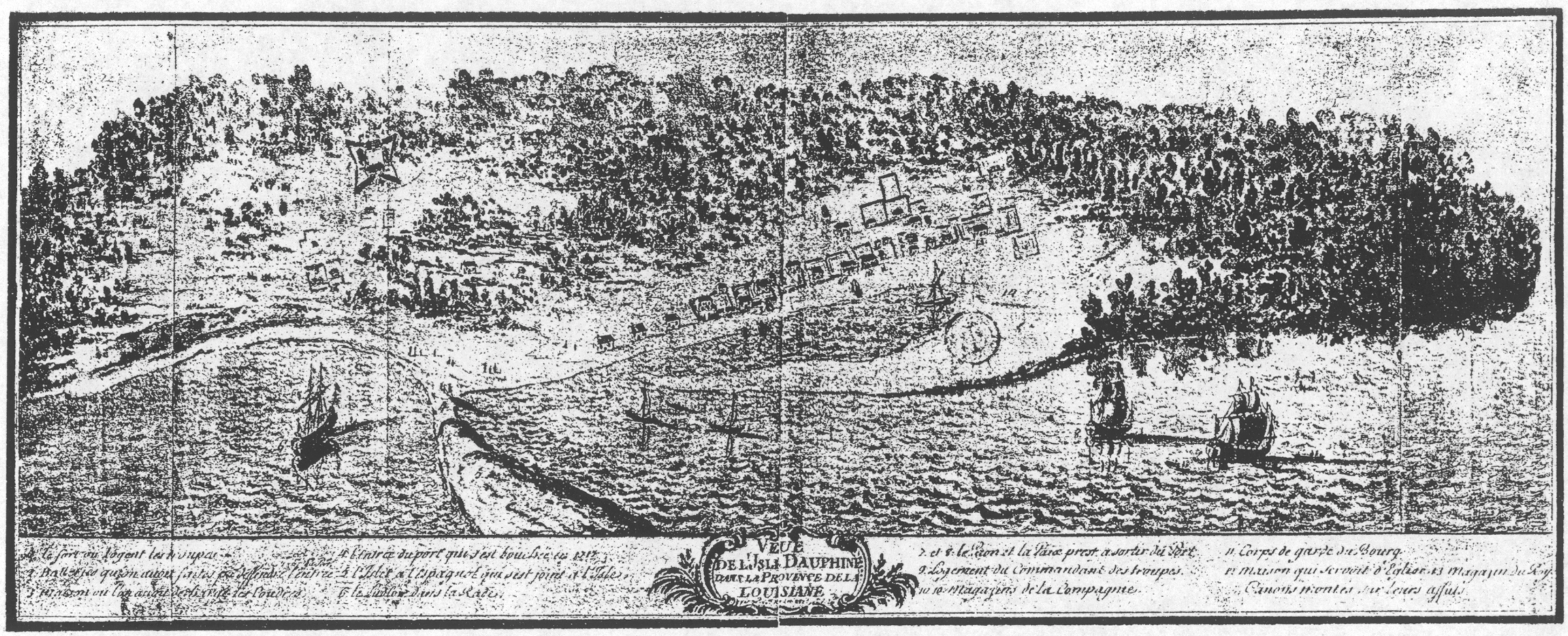


Figure 13.--View of Dauphin Island, Alabama, in the year 1717 (modified from Hamilton, 1897).

Figure 14.--Map of Dauphin Island, Alabama, in the year 1718 (modified from Higginbotham, 1977).

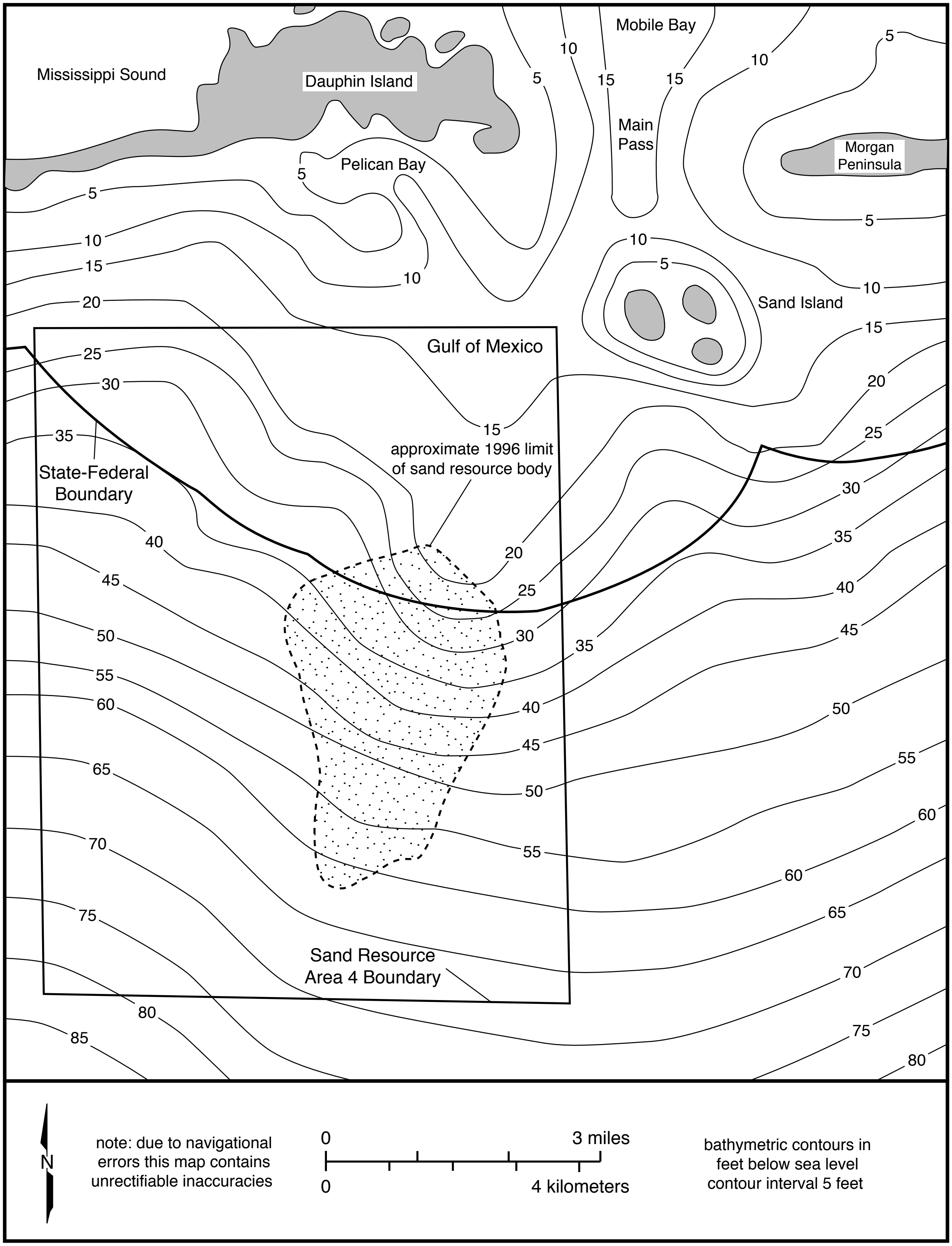


Figure 15.--Bathymetry of study area, 1732 (modified from Hamilton, 1897).

hurricanes, 1722 and 1732, occurred during the period 1711-32, but no information is available as to their effects on coastal Alabama (U.S. Army Corps of Engineers, 1967).

George Gauld, a cartographer and surveyor for the British Admiralty, mapped Alabama coastal geography and water depths in 1768 (Ware, 1982). His nautical chart was published by the British Admiralty in 1771 and appears in Hamilton (1897). Figure 16 is the finished 1771 study area bathymetric map. Bathymetry in area 4 is shallower and the sea floor gradient gentler than in 1732. Water depth increases toward the south. Sand Island is absent, but Pelican Island is present as two separate islands. A pass between Pelican Island and Dauphin Island exists with water depths approaching that of the early 1700's.

The deep area southwest of Morgan Peninsula (fig. 16) is an ebb-flood tidal channel (fig. 3) that was mapped by Gauld. This channel does not appear on the 1732 bathymetric map (fig. 15). From the late 1600's to 1768, the standard procedure for entering Mobile Bay was to sail west across the shallow bar guarding eastern Main Pass, then around the western tip of Morgan Peninsula and into deeper water toward the center of Main Pass, and then sail north into Mobile Bay (Hamilton, 1897; Ware, 1982). This path would take a vessel directly over the channel shown on figure 16. Water depths over the bar ranged from 5-13 ft, with the deeper waters of Main Pass and southern Mobile Bay reported to be 10-15 ft (Hamilton, 1897). It is likely that the channel was much shallower before 1768, and deepened considerably at some time between 1732 and 1768. In addition to the deepening of the channel, an area of sediment accumulation appears south of Morgan Peninsula and the present-day State-Federal Boundary (fig. 16).

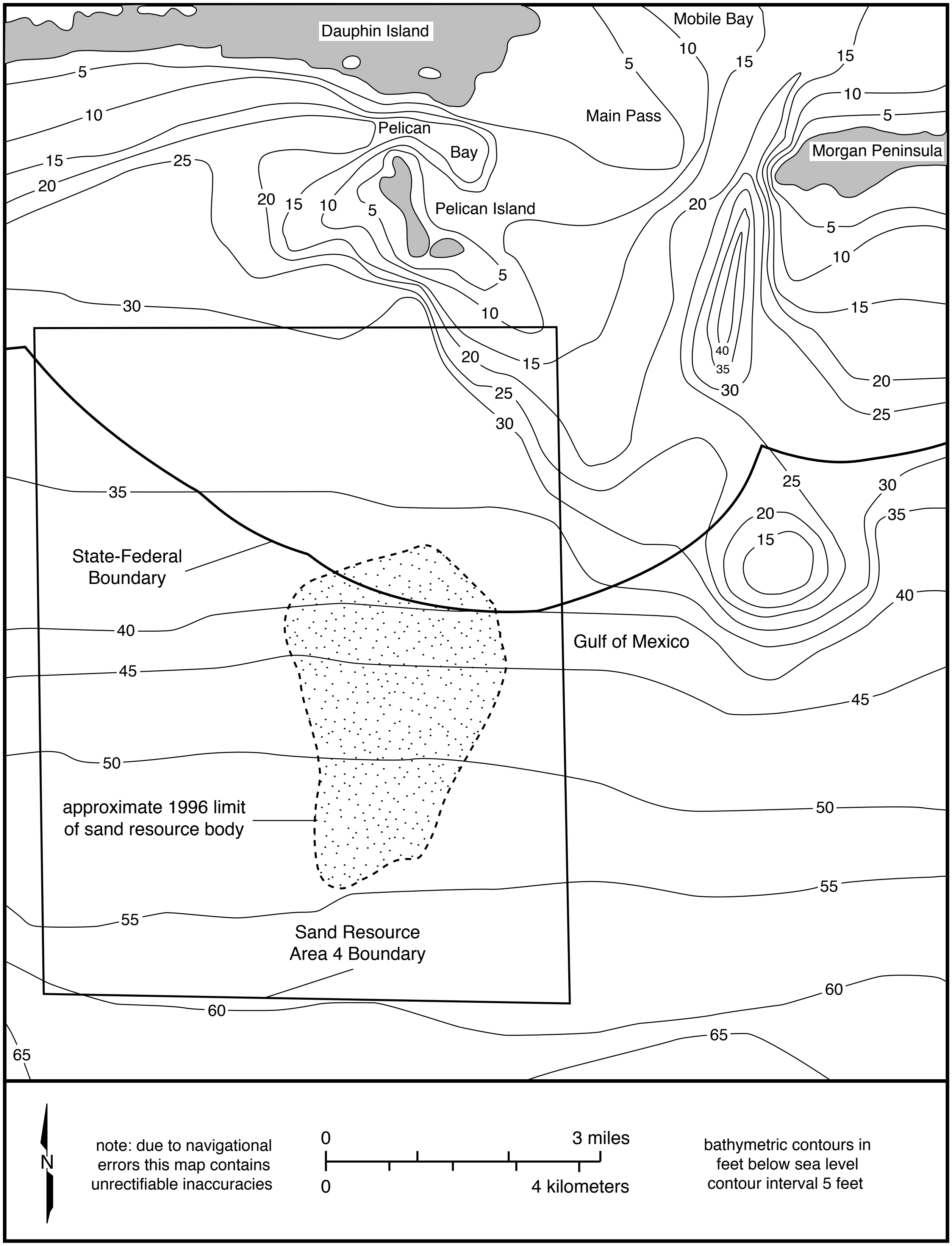


Figure 16.--Bathymetry of study area, 1771 (modified from Hamilton, 1897).

From 1732 to 1771, four hurricanes occurred along the east-central Gulf of Mexico coast (U.S. Army Corps of Engineers, 1967). The hurricanes of 1736, 1759, and 1766 affected principally Pensacola, with perhaps some minor damage along the Alabama coast (U.S. Army Corps of Engineers, 1967). However, the hurricane of September 12, 1740 inflicted heavy damage on Mobile and Dauphin Island (Hamilton, 1897). The formation of Petit Bois Pass is attributed to this hurricane (Otvos, 1979). The pass is shown on the original 1771 map, but not on the original 1732 map. It is reported that half of Dauphin island was washed away by the storm (Hamilton, 1897). In 1768, Gauld may have observed evidence of the 1740 hurricane damage to Dauphin Island. He stated that the eastern third of Dauphin Island was covered by a forest of thick pine trees (Ware, 1982). However, he noted that the narrow western end of the Island contained nothing but dead pine trees for 4 mi (Ware, 1982). The original 1732 map portrays Dauphin Island in its present-day shape (fig. 7), but the original 1771 map shows the eastern third of Dauphin Island separated from its western two-thirds by a pass. In addition, the western portion of the Island is characterized as a shoal in 1771. It is possible that the hurricane of 1740 scoured the ebb-flood tidal channel southwest of Morgan Peninsula, and deposited sediments south of Morgan Peninsula and the present-day State-Federal Boundary (fig. 16).

In 1732, the littoral drift system could transport sediment westward from Morgan Peninsula, across Main Pass, and down the southern shoreline of Dauphin Island (fig. 15). However, in 1771, the deep ebb-flood tidal channel southwest of Morgan Peninsula would act as a barrier to longshore transport of sediment across Main Pass (fig. 16). Ebb-tidal currents in the channel would force sediment transport southward toward the sediment depositional center shown in the east-central part of the study area (fig. 16). Fair-weather wave approach is predominantly from the southeast. The waves would reestablish a littoral drift system which carries and deposits sediment northwestward along the western edge of the ebb-tidal delta of Mobile Bay. The sedimentary deposit, a complex of shoals and bars that includes emerged portions (Pelican and Sand Islands), grew by accretion at its northern end, culminating with its approach to Dauphin Island (fig. 16). Tidal flow through the narrow pass between Pelican and Dauphin Islands maintained a 15-20 ft channel in 1771. Gulf of Mexico wave trains are refracted by Pelican Island to impinge on the southeastern shoreline of Dauphin Island. Wave energy is focused by the acute angle formed by Dauphin and Pelican Islands, resulting in erosion of the southeastern shoreline of Dauphin Island, as evidenced by the broad curvature of the Dauphin Island shoreline (fig. 16). Waves reflected by Dauphin Island combined with ebb-tidal flow through the pass, cause the formation of a recurved spit off the northern end of Pelican Island (sea floor due west of Pelican Island - fig. 16). Sediment eroded from the Dauphin Island shoreline is probably carried westward along the Island by littoral drift.

One of the earliest maps showing detailed soundings of the study area is a chart of the northern Gulf of Mexico produced by B. Romans between 1772/73 and 1775 for the Marine Society of the City of New York (Romans, 1772/73-1775). His data were used to draft the contoured bathymetric map shown in figure 17.

Romans' map shows several noteworthy features. First, Pelican Island is present and the shoal to its southeast may represent Sand Island (fig. 17). The deep ebb-flood tidal channel, seen on the 1771 bathymetric map (fig. 16), has migrated into Main Pass and can be seen north of the western end of Morgan Peninsula (fig. 17). The deepest point within the channel is 55 ft. With the absence of the channel, the Morgan Peninsula littoral drift system can transport

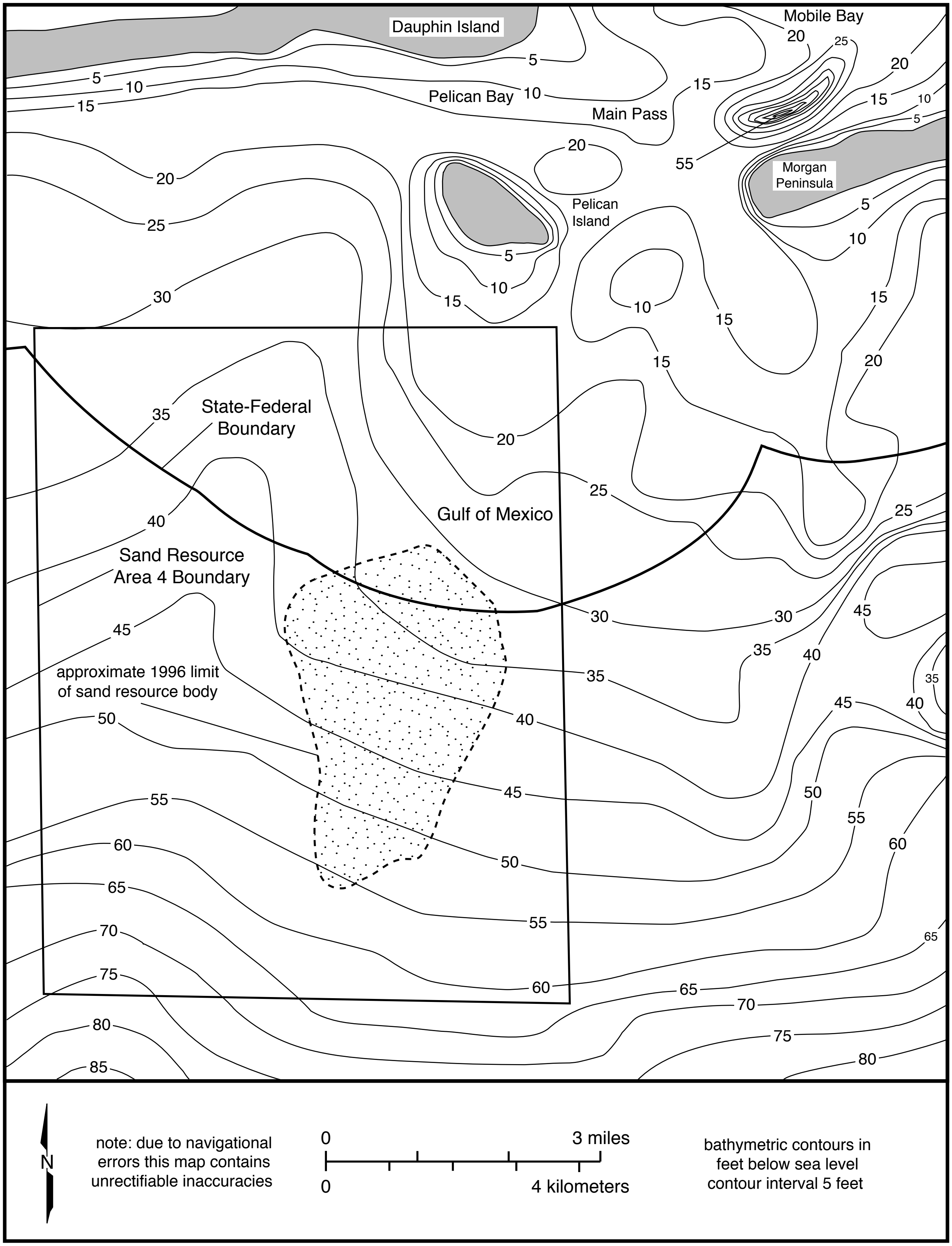


Figure 17.--Bathymetry of study area, 1775 (modified from Romans, 1772/73-1775).

sediment northwestward across the ebb-tidal delta of Mobile Bay to feed Pelican Island, and on to Dauphin Island (fig. 17). The isobaths show that the sediment depositional center (in the east-central portion of the study area - fig. 16) has migrated toward Pelican Island (fig. 17). Comparison of the isobaths between 1771 (fig. 16) and 1775 (fig. 17) indicates that the ebb-tidal delta has shallowed and expanded southeastward with the increased sedimentation associated with the migration of the sediment depositional center. The pass between Pelican and Dauphin Islands has widened and shallowed with the influx of sediment from the southeast (fig. 17). Water depths in area 4 appear to have deepened between 1771 and 1775. Nearshore bathymetry indicates that sediment transport to and along the Dauphin Island shoreline appears to have shifted the shoreline from an erosive to accretionary regime. The original 1775 map shows Dauphin Island in the 1771 breached state.

From 1771 to 1775, only the hurricane of September 4, 1772 impacted the Alabama coast (U.S. Army Corps of Engineers, 1967). The hurricane caused considerable damage in Mobile, and along the Gulf of Mexico shoreline (U.S. Army Corps of Engineers, 1967).

The soundings database for the 1822 navigation chart (U.S. Department of War, 1822) is limited to the sea floor between Main Pass, and Pelican and Sand Islands. These data are presented as the 1822 bathymetric map (fig. 18). The deep ebb-flood tidal channel north of the western tip of Morgan Peninsula has lengthened considerably toward the south-southwest, almost reaching Sand Island (fig. 18). In addition, Pelican Bay has deepened since 1775, and the western half of Main Pass has shallowed since that time. The pass between Pelican and Dauphin Islands has narrowed and shallowed. The isobaths in the pass show accretion at the northern end of Pelican Island and spit growth from Dauphin Island down toward Pelican Island (fig. 18).

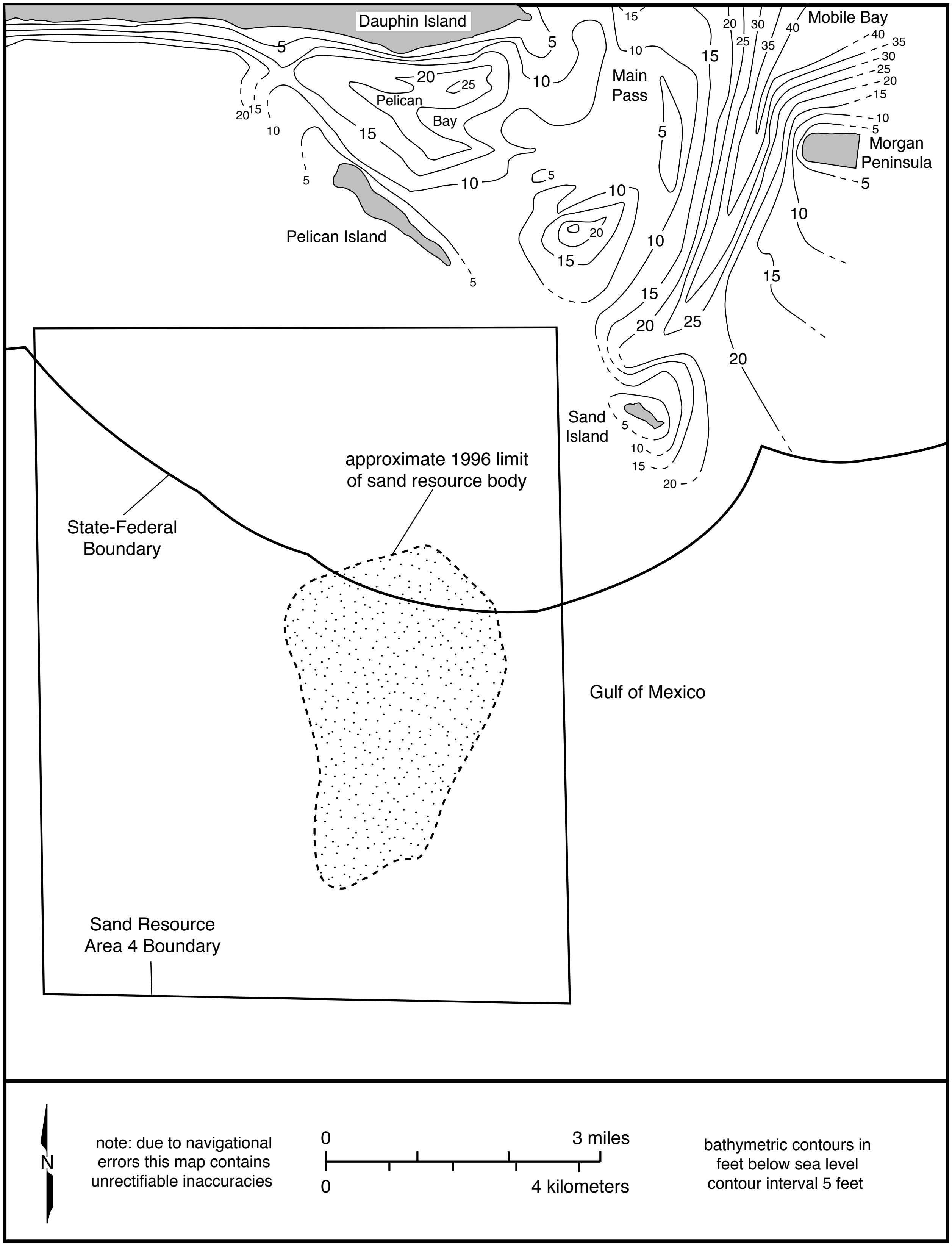


Figure 18.--Bathymetry of study area, 1822 (modified from U.S. Department of War, 1822).

As was seen in 1771 (fig. 17), the presence of the deep channel west of Morgan Peninsula in 1822 caused the longshore transport system along Morgan Peninsula to be directed toward the southeast. The presence of Sand Island, the accretion of Pelican Island, and the deepening of Pelican Bay, are indications that the sediment transport pathway moved northwestward along the western edge of the ebb-tidal delta of Mobile Bay. The system encountered Dauphin Island west of Pelican Bay.

The concavity of the Dauphin Island Gulf of Mexico shoreline, spit growth, and close spacing of nearshore isobaths suggest an erosive shoreline (fig. 18). Gulf of Mexico wave trains are refracted by Pelican Island and impinged on the southeastern shoreline of Dauphin Island. Wave energy is focused by the acute angle formed by Dauphin and Pelican Islands, resulting in erosion of the southeastern shoreline of Dauphin Island. Sediment eroded from the Dauphin Island shoreline is probably carried westward along the Island by littoral drift.

During the 47-year period, 1775 to 1822, eleven hurricanes affected the Alabama coast (U.S. Army Corps of Engineers, 1967). However, only the hurricane of 1822 impacted coastal Alabama, but accounts of its effects are unavailable (U.S. Army Corps of Engineers, 1967). The original 1822 map shows Dauphin Island in the 1771 and 1775 breached state.

The U.S. Coast and Geodetic Survey was established in the 1840's, under the Department of Commerce, to conduct hydrographic and topographic surveys of the United States coastline. Hydrographic charts showing water depths and coastal geography of the Alabama coast were first produced in 1847-48. Figure 19 is an 1848 bathymetric map of the study area constructed from the soundings database.

From 1822-48, the ebb-flood tidal channel west of Morgan Peninsula has lengthened toward the south, past Sand Island (fig. 19). Also, the channel

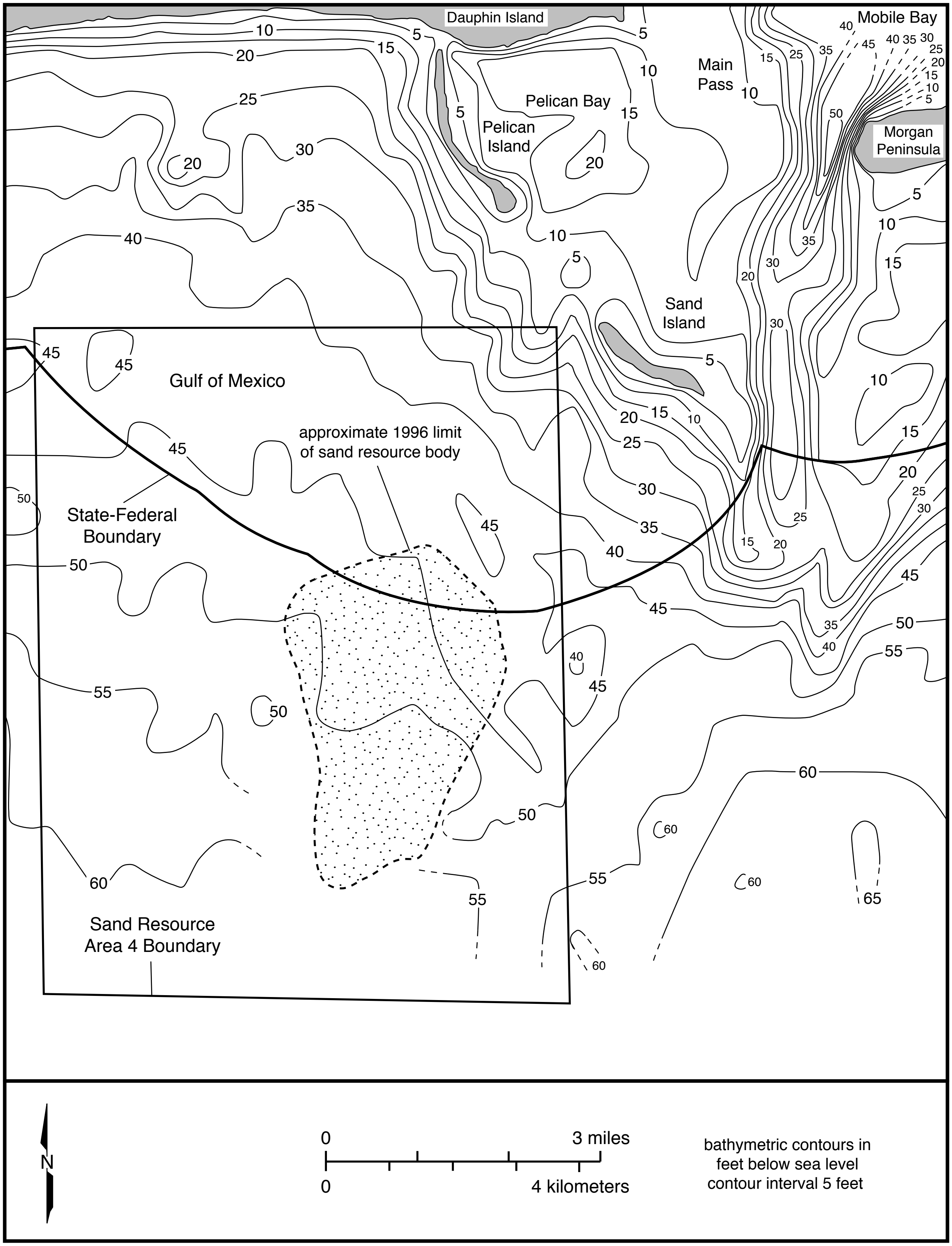


Figure 19.--Bathymetry of study area, 1848 (modified from U.S. Coast and Geodetic Survey, 1847-48).

deepened over its length, reaching greater than 50 ft due west of Morgan Peninsula. Sediment transport along the western margin of the ebb-tidal delta of Mobile Bay has resulted in the migration of Pelican and Sand Islands toward the north-northeast (fig. 19). Pelican Island has almost become attached to Dauphin Island. The configuration of Dauphin and Pelican Islands in 1848 is almost identical to that seen in 1718 (fig. 14). Waves refracted around the western shoreline of Pelican Island caused the Island to adopt a crescent shape (fig. 19). The shape of the Dauphin Island shoreline north of Pelican Bay, and Pelican Bay bathymetry, indicate erosion near the eastern tip of Dauphin Island and accretion near Pelican Island. In the absence of longshore transported sand from Morgan Peninsula, Gulf of Mexico waves and tidal currents erode the eastern tip of Dauphin Island and transport the eroded sediment westward down the coast (fig. 19). Pelican Island interrupts the littoral drift, and much of the eroded sediment nourishes the Dauphin Island shoreline east of Pelican Island (fig. 19). The nearshore bathymetry, and concavity of the Dauphin Island shoreline west of Pelican Island, indicate a shoreline undergoing erosion. Sediment eroded from the Dauphin Island shoreline was probably carried westward along the Island by littoral drift.

Bathymetry in area 4 shows an evenly sloping sea floor that deepens toward the southwest. The original 1847-48 hydrographic chart shows that Dauphin Island was no longer breached as it was in 1822. Four hurricanes occurred during the period 1822-48 that affected coastal Alabama (U.S. Army Corps of Engineers, 1967). Detailed accounts of their effects on the Alabama coast are unavailable, but were probably minimal (U.S. Army Corps of Engineers, 1981) based on the principal areas affected by the storms (U.S. Army Corps of Engineers, 1967).

BATHYMETRIC AND BATHYMETRIC DIFFERENCED MAPS 1848-1997

The bathymetric map of 1892 (fig. 20) shows that Pelican and Sand Islands have migrated toward the southeast since 1848 (fig. 19). Other notable changes include the overall deepening of the ebb-flood tidal channel west and southwest of Morgan Peninsula, and the shallowing of Pelican Bay. Area 4 is unchanged overall. The 1848-92 bathymetric differencing map (fig. 21) graphically portrays the deepening of the channel, shallowing of Pelican Bay, and the accretion of sediment on the eastern margin of the ebb-tidal delta of Mobile Bay, east of the channel. Tidal currents and Gulf of Mexico waves sculpted Sand Island into a crescent shape (fig. 20). Littoral drift appears to not only have transported sediment southeastward along the eastern side of the channel, but across the channel between the two deep channel endpoints (figs. 20 and 21). Sediment was deposited between Sand Island and the channel, and south of Sand Island (fig. 21). Littoral drift probably moved sediment along both the southern and northern shorelines of Pelican and Sand Islands. The southern shoreline of Dauphin Island appeared to be dominantly accretionary (fig. 21). The conical-shaped accumulation of sediment in the northeast corner of area 4 may be fictitious, as a single data point of +14 ft produces this bathymetric feature (fig. 21). The original 1892 hydrographic map shows Dauphin Island as a continuous island (unbreached).

Between 1848-92, the U.S. Army Corps of Engineers (1967) lists ten hurricanes and one tropical storm as having affected coastal Alabama. The hurricanes of 1852, 1860, 1870, 1877, 1880, 1882, 1887, and 1888, inflicted damage to coastal Alabama from high winds, river flooding due to heavy rainfall, and storm surge (U.S. Army Corps of Engineers, 1967). The city of

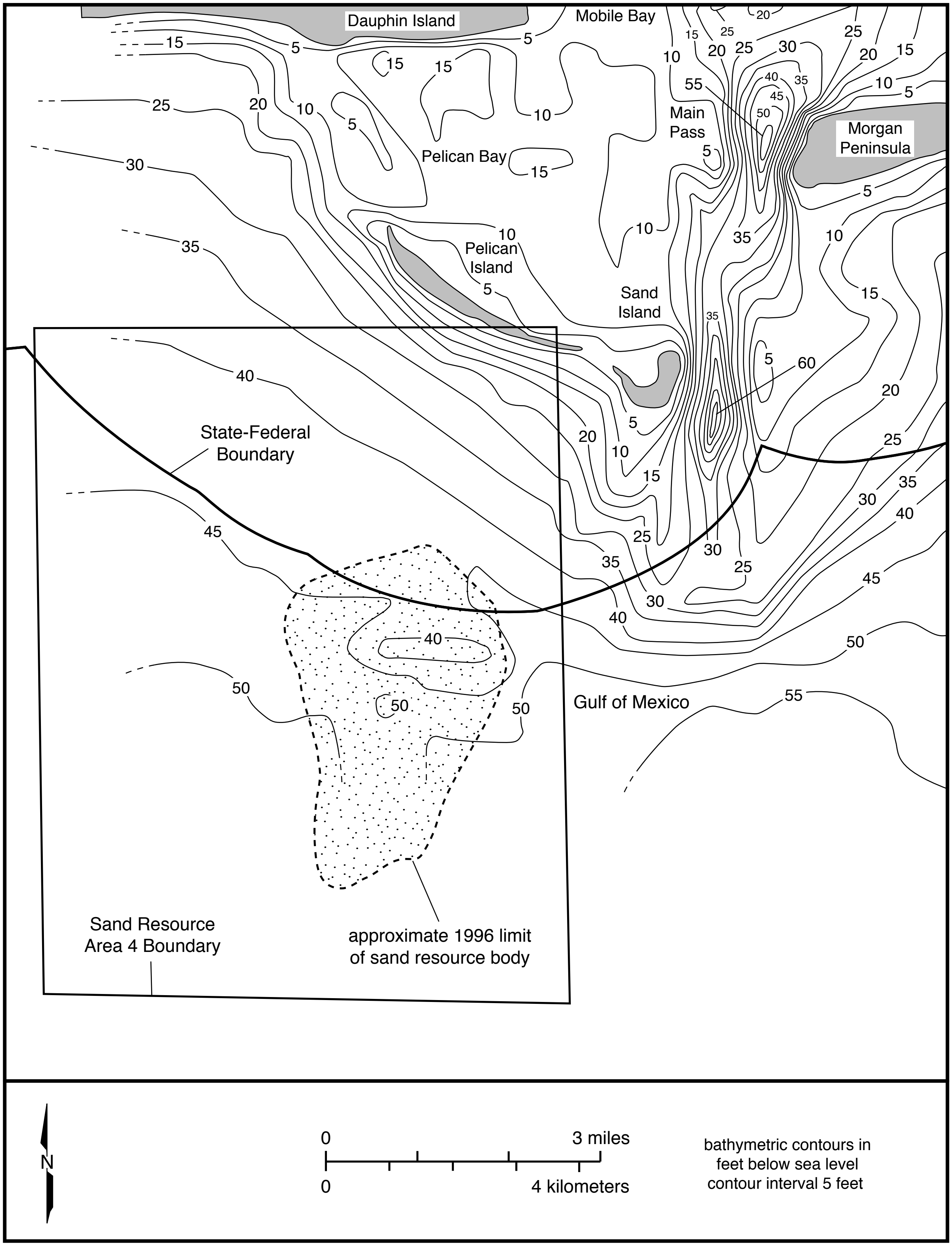


Figure 20.--Bathymetry of study area, 1892 (modified from U.S. Coast and Geodetic Survey, 1892).

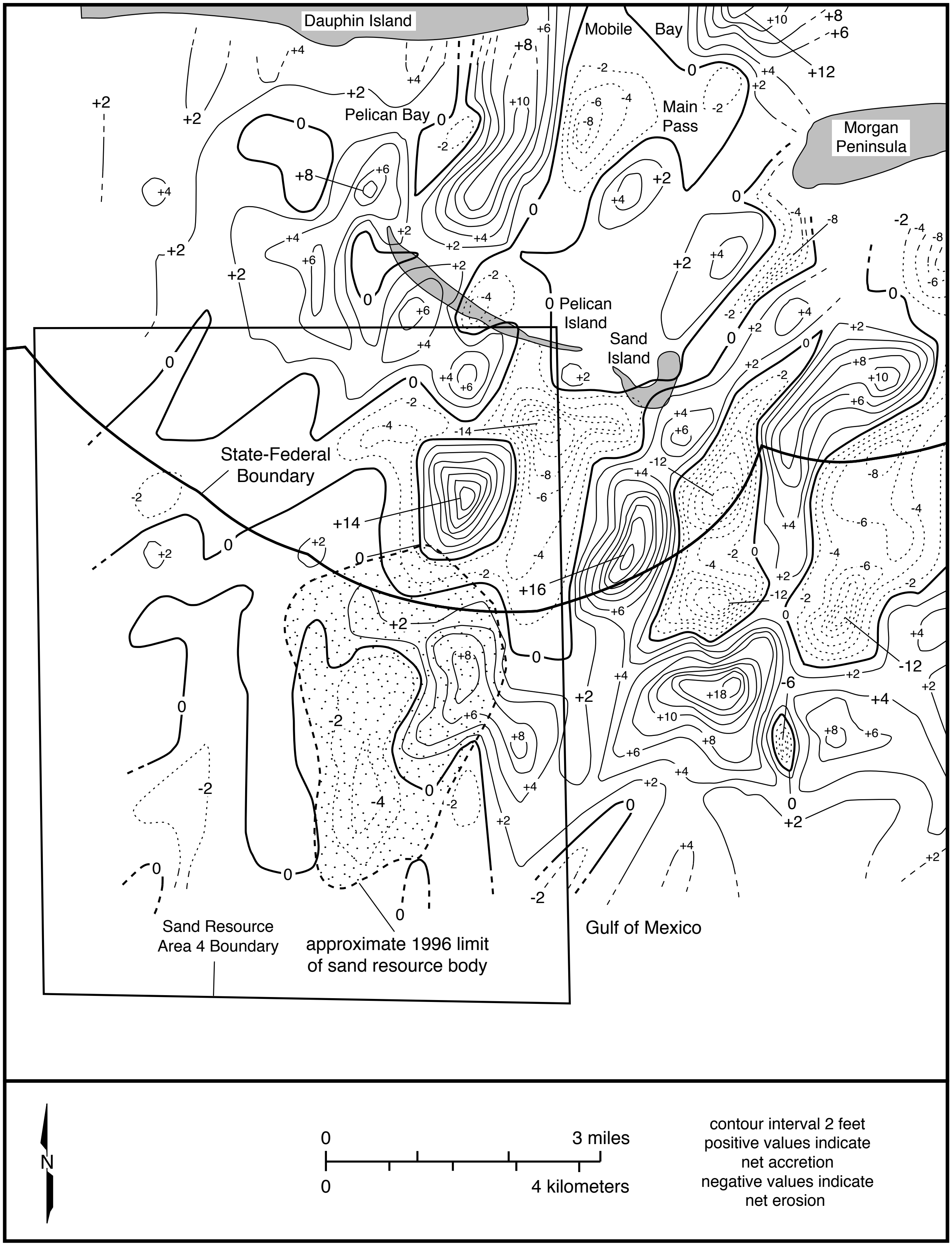


Figure 21.--Bathymetric differencing map of study area, 1848 to 1892.

Mobile was hard hit by these storms, but no information is available concerning the storms' affects on the study area.

The federal government began dredging operations in coastal Alabama in 1826 (Bisbort, 1957). However, up until 1870, dredging was confined to channel improvements and removing obstructions in the Port of Mobile and mouth of the Mobile-Tensaw River system (Bisbort, 1957). Beginning in 1870, and continuing to the present-day, the focus has been the widening and deepening of Mobile Bay shipping and Mobile-Tensaw River channels. It is thought that the U.S. Army Corps of Engineers did not begin dredging operations on the ebb-tidal delta of Mobile Bay until the 1890's (S. Rees, 1997, oral communication). In addition, because of the existence of a natural, deep channel due west of Morgan Peninsula (ebb-flood tidal channel), the U.S. Army Corps of Engineers has never had to dredge that area (S. Rees, 1997, oral communication). It is possible that the U.S. Army Corps of Engineers deepened the southern end of the channel shown on figure 20. It is unlikely the channel was dredged by the U.S. Army Corps of Engineers. Between 1870 and 1892, navigation channels were stipulated by the federal government to have a minimum depth of 23 ft (Bisbort, 1957). Because, the channel was already at a minimum of 25 ft along its length (figs. 19, 20) it would not make sense to dredge the channel to 55 or 60 ft (fig. 20). It is concluded that the southern end of the channel was probably deepened by hurricane storm surge, intensified ebb-tidal currents, and hurricane rainfall discharge from Mobile Bay.

The 1908 bathymetric map of the study area (fig. 22) shows the almost complete infilling of the ebb-flood tidal channel west and southwest of Morgan Peninsula. In addition, Pelican and Sand Islands have migrated and lengthened by accretionary growth at their northern ends (fig. 22). The pass between Pelican and Dauphin Islands has narrowed considerably. The

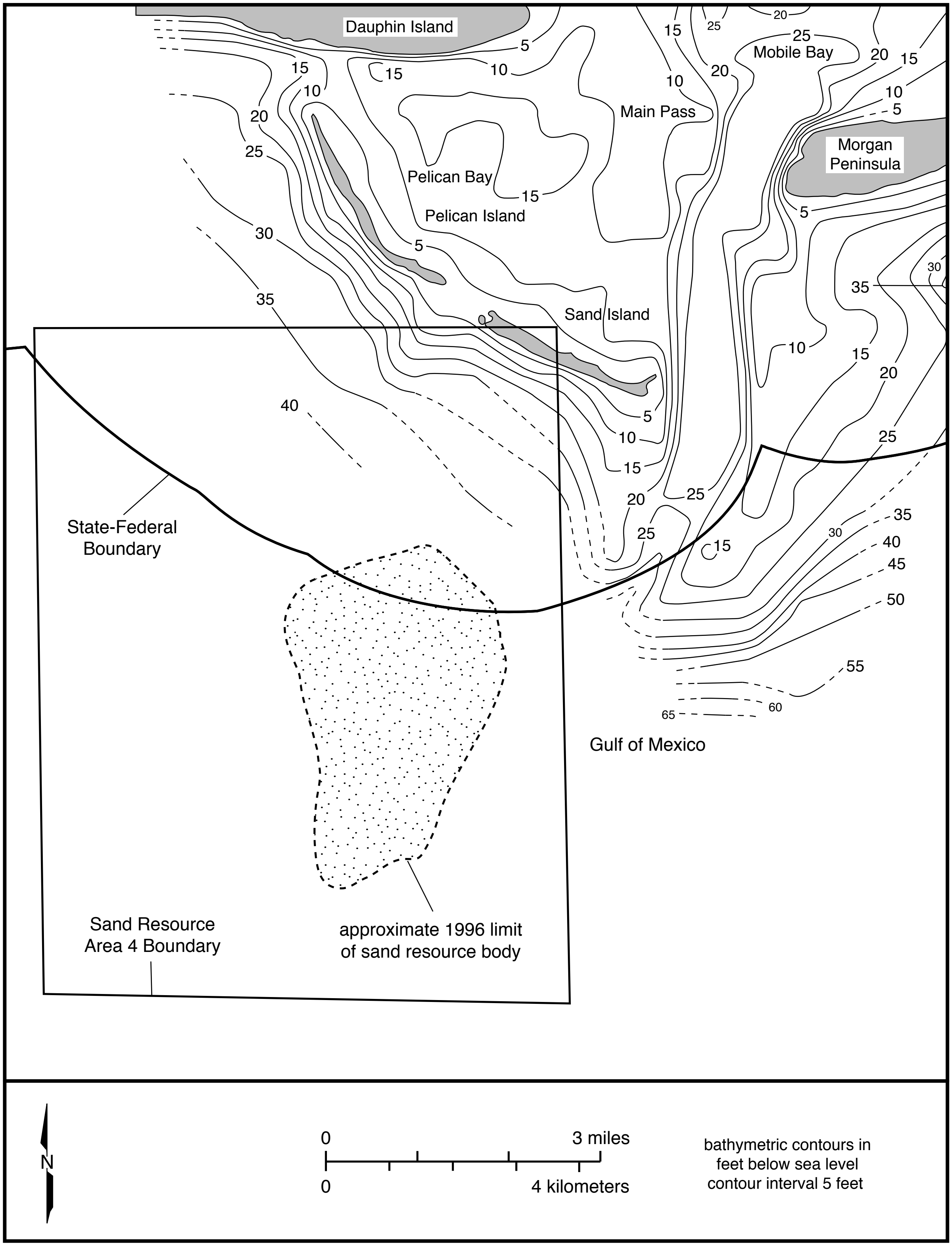


Figure 22.--Bathymetry of study area, 1908 (modified from U.S. Coast and Geodetic Survey, 1908).

increase in tidal current velocity in the pass is indicated by the deepening of the pass and Pelican Bay. The presence of a wave and tidal current-built submerged spit is revealed by bathymetry at the northern end of Pelican Island (fig. 22). The original 1908 hydrographic map does not indicate whether Dauphin Island is a continuous island as it is today or breached as it was in 1822. Despite an incomplete soundings database for area 4, it appears that the bathymetry has not changed much from 1892 to 1908 (figs. 20, 22).

The 1892-1908 bathymetric differencing map (fig. 23) shows the infilling of the channel using sediment derived from the Morgan Peninsula littoral drift system and erosion of channel margins. The westward sediment transport pathway along Sand and Pelican Islands, and the accretionary growth of the Islands are reflected by the positive contours. The deepening of Pelican Bay and the accretionary state of the Dauphin Island Gulf of Mexico shoreline north of Pelican Bay are indicated by the convex shoreline shape and nearshore positive contours (fig. 23). Gulf of Mexico wave refraction sculpted Pelican Island into a crescent shape. The concentration of wave energy at the acute angle formed by Dauphin and Pelican Islands resulted in erosion of the Dauphin Island shoreline at that point, as reflected by the nearshore negative contours (fig. 23).

One hurricane and seven tropical storms affected coastal Alabama during the period 1892-1908 (U.S. Army Corps of Engineers, 1967). The hurricane of October 2, 1893, and tropical storm of August 15, 1901, inflicted wind and storm surge flood damage on Mobile (U.S. Army Corps of Engineers, 1967). The hurricane of September 27, 1906, devastated coastal Alabama, and is considered by the U.S. Army Corps of Engineers (1967) hurricane study report to be the most destructive storm in the history of Mobile up to that time (1967). The hurricane caused extensive wind and wave damage, and widespread

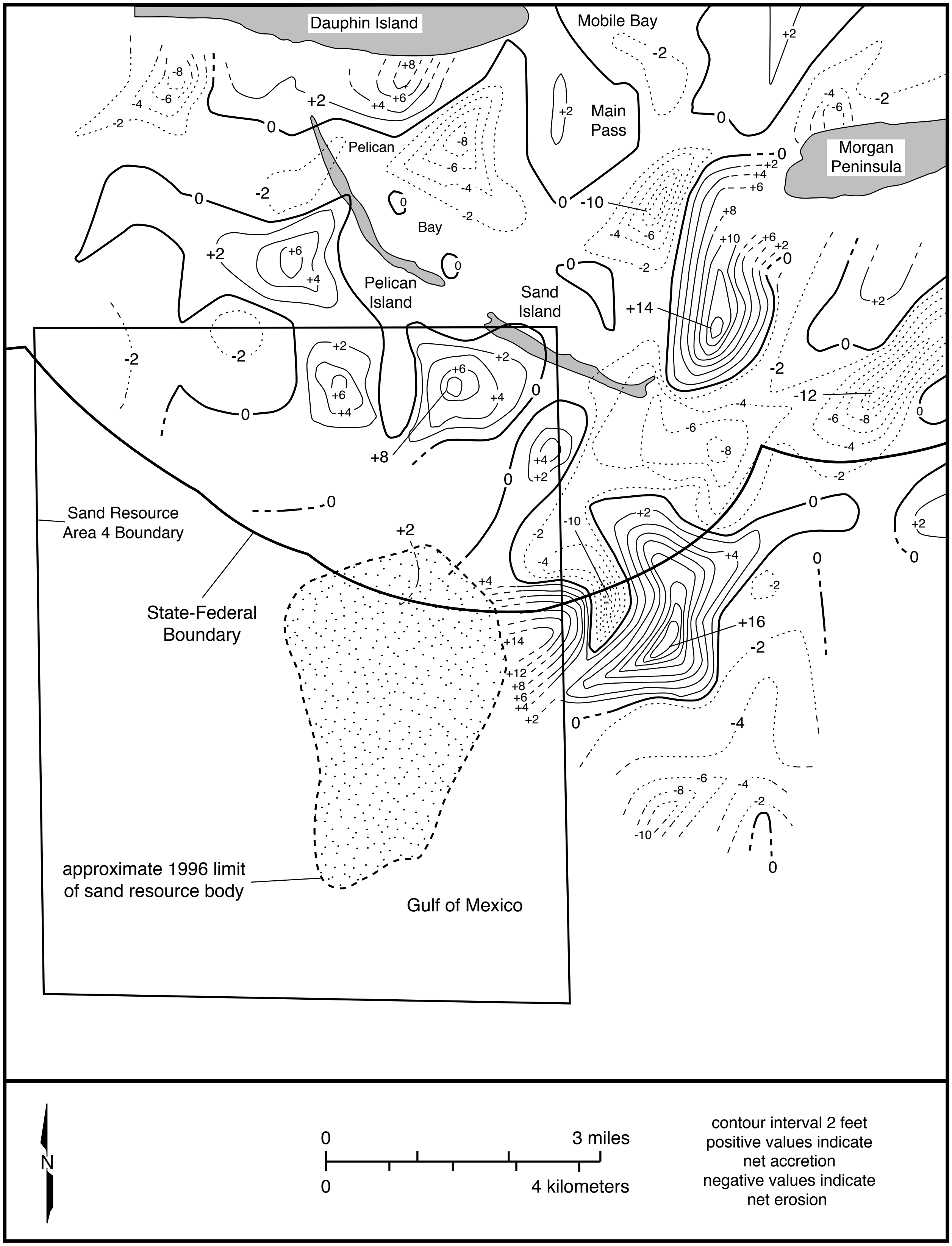


Figure 23.--Bathymetric differencing map of study area, 1892 to 1908.

flooding from rainfall and tidal surge. Based on the behavior and path of the 1906 hurricane, the storm could be responsible for the infilling of the ebb-flood tidal channel.

In 1918, the bathymetry of the study area shows that the ebb-flood tidal channel east and southeast of Morgan Peninsula has returned to its 1892 configuration (fig. 24). Pelican and Sand Islands have diminished in size, and the pass between Dauphin and Pelican Islands has narrowed and become shallower (fig. 24). The sediment transport pathway appears to be southward along the eastern margin of the channel, around the southern end of the channel, and northeastward along the western margin of the ebb-tidal delta of Mobile Bay, including Pelican and Sand Islands. A pass has separated the eastern one-third of Dauphin Island from its western two-thirds (fig. 24). The nearshore bathymetry south of the pass indicates the presence of an ebb-tidal delta. There is a recurved spit at what was then the west end of Dauphin Island. This spit indicates that the littoral drift is transporting sediment westward along the Gulf of Mexico shoreline of Dauphin Island. The shape of the spit also indicates that flood-tidal currents move through the eastern side of the pass.

The 1908-18 bathymetric differencing map shows widespread erosion of the study area (fig. 25). Net accretion occurred east of the ebb-flood tidal channel, in Pelican Bay, at the north end of Pelican Island, in Main Pass, and formed the food-tidal delta of the pass at the west end of Dauphin Island.

During the period 1908-18, five hurricanes affected coastal Alabama (U.S. Army Corps of Engineers, 1967). High wind, heavy rainfall, and tidal surge caused by the hurricanes of July 5, 1916, and September 28, 1917, inflicted damage to Mobile and the Alabama Gulf of Mexico shoreline.

The bathymetric map of 1920 covers the southern half of the study area (fig. 26). Water depth increases in a south-southeasterly direction across area 4.

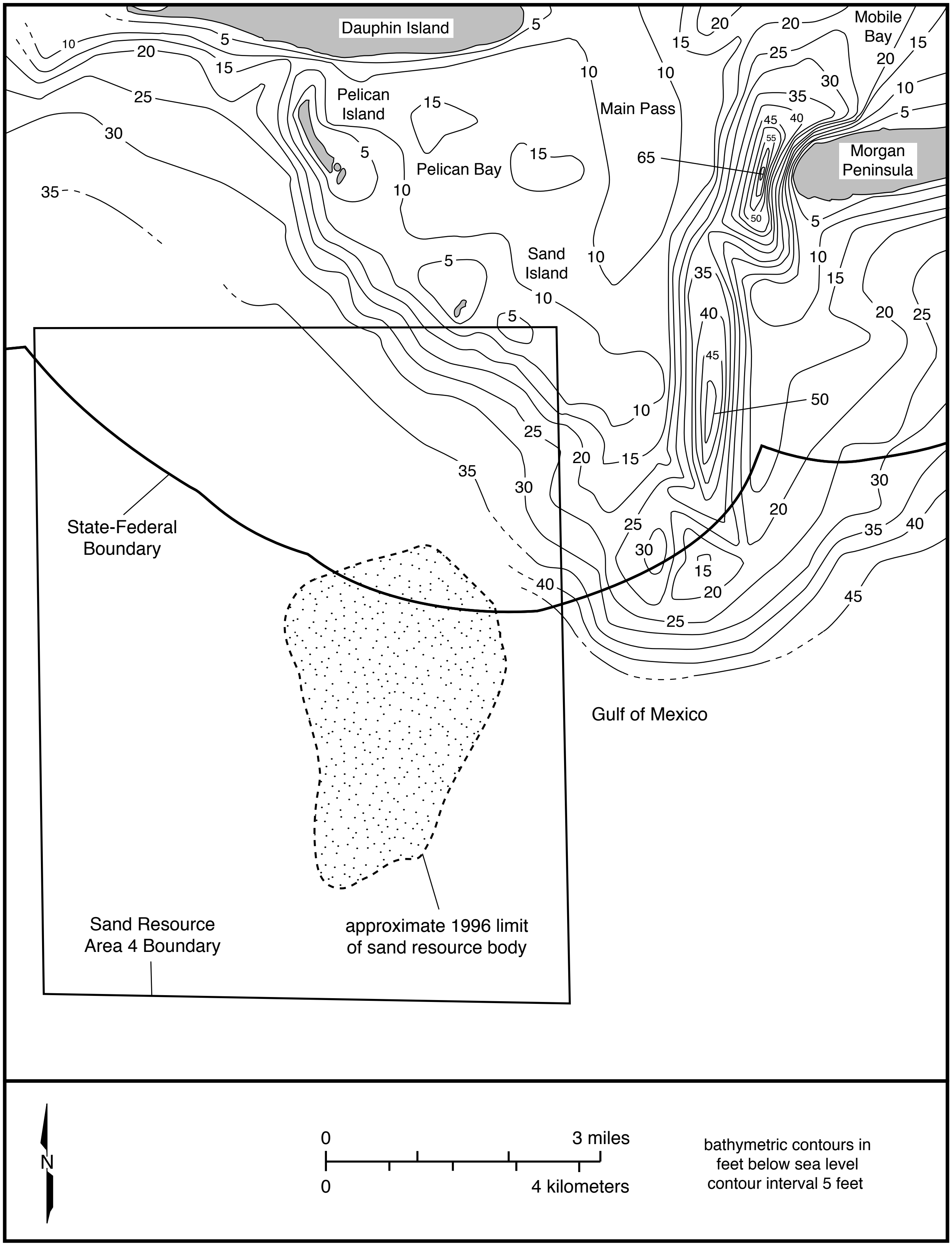


Figure 24.--Bathymetry of study area, 1918 (modified from U.S. Coast and Geodetic Chart, 1917-18).

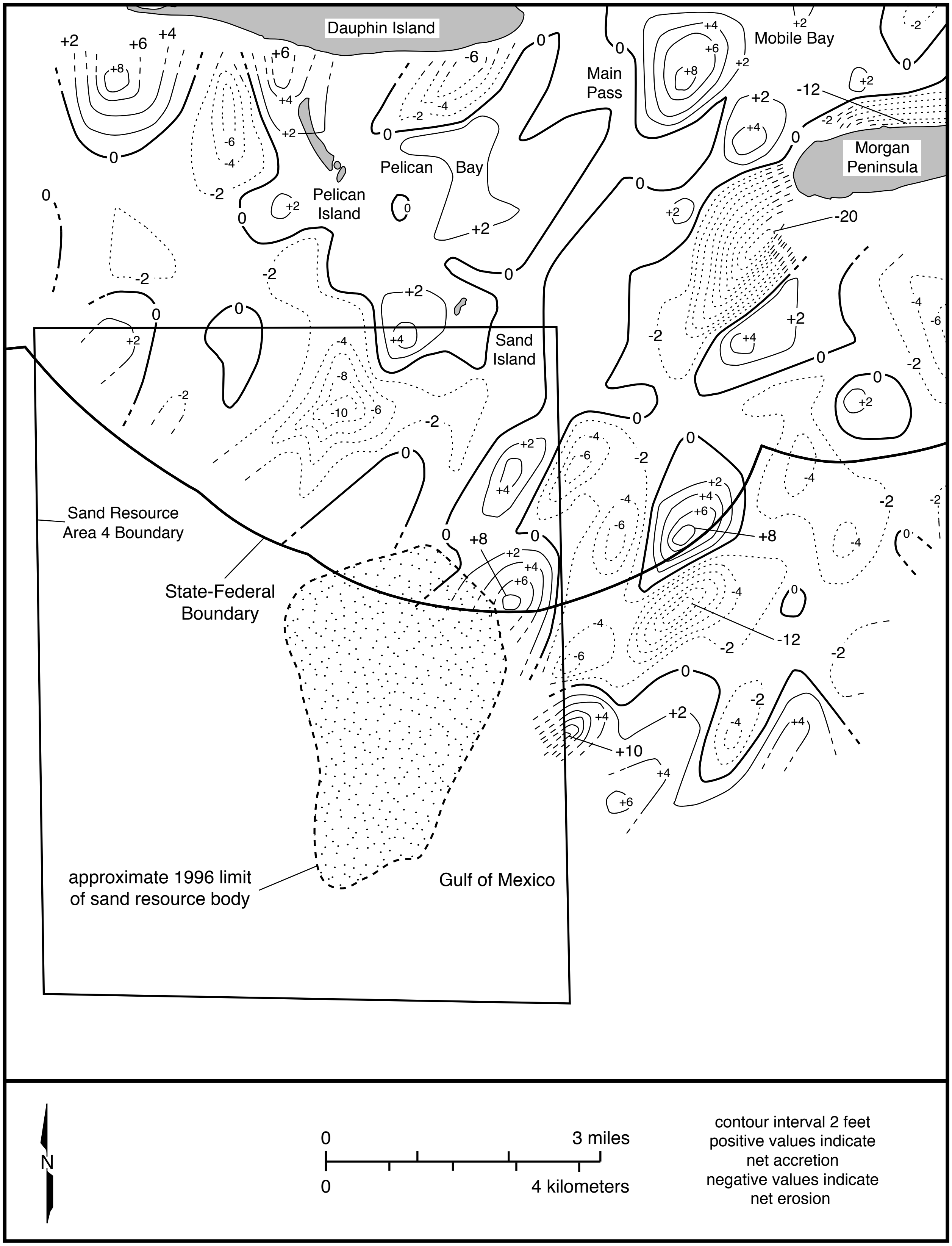


Figure 25.--Bathymetric differencing map of study area, 1908 to 1918.

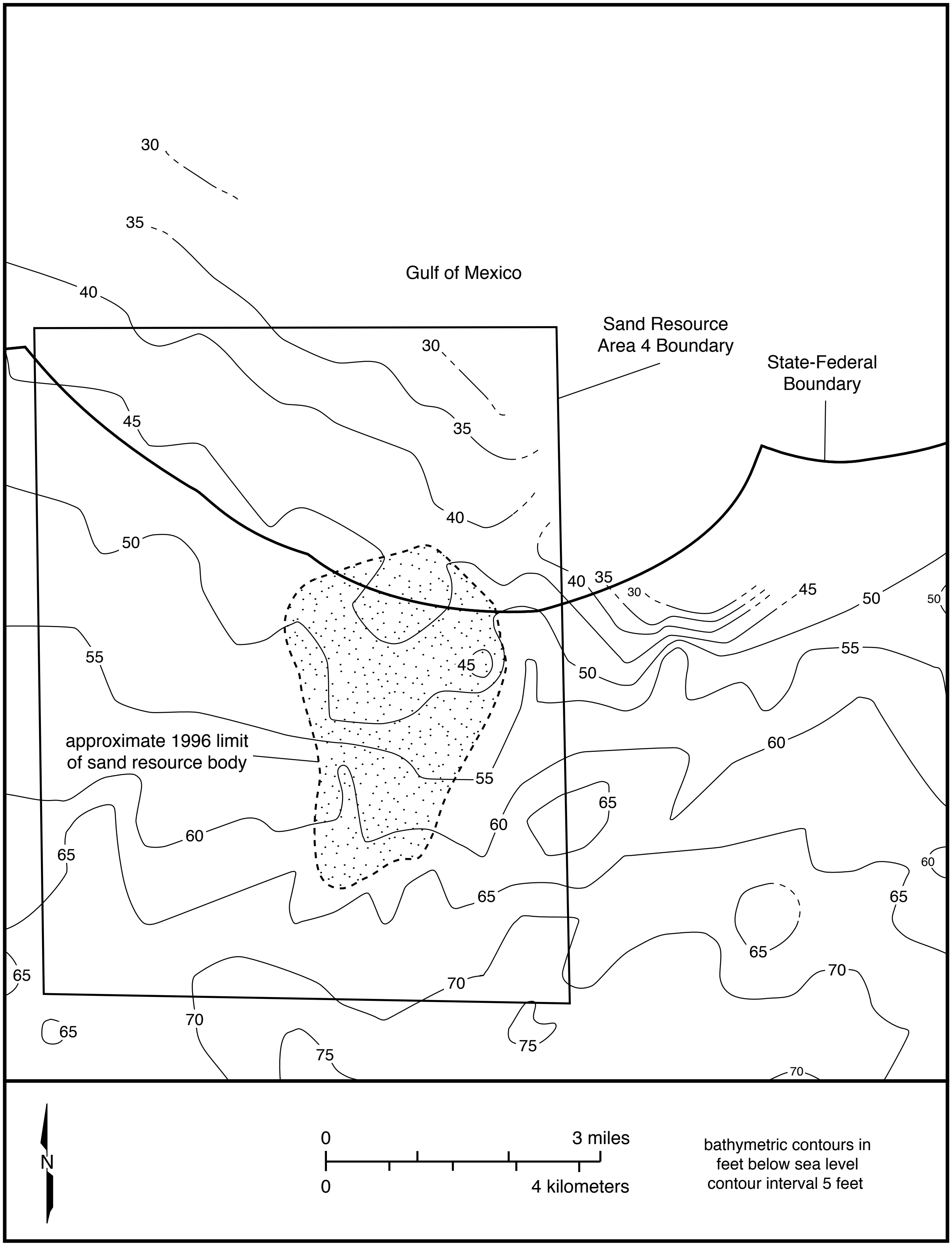


Figure 26.--Bathymetry of study area, 1920 (modified from U.S. Coast and Geodetic Survey, 1920).

Comparison of the overlap in bathymetry between figures 24 and 26 indicate that the bathymetry in the southern half of the study area in 1918 was nearly identical to that seen in 1920. Figure 27 is a bathymetric differencing map for 1918-20. The map indicates widespread erosion, as was seen for the 1908-18 bathymetric differencing map (figs. 25, 27). One tropical storm occurred during 1918-20 which did not impact the Alabama coast.

The 1927 bathymetric map (fig. 28) is virtually identical to those of 1918 (fig. 24) and 1920 (fig. 26). Even the size, shape, and location of the 1927 Pelican and Sand Islands are almost the same as in 1918. In 1927, Dauphin Island was still breached by a pass, but a flood-tidal delta, present in 1918, no longer exists (fig. 28). Some accretion has occurred around the margin of the ebb-tidal delta of Mobile Bay, and the pass between Dauphin and Pelican Islands has shallowed (fig. 28). The stability of the study area between 1918 and 1927 is reflected by the 1920-27 bathymetric differencing map (fig. 29). The northern margin of the differencing contours shows the net accretion of sediment around the margin of the ebb-tidal delta of Mobile Bay.

The 1927 nautical chart indicates for the first time, the presence of a dredged channel (Mobile Bay entrance channel) at the southern apex of the ebb-tidal delta of Mobile Bay. The dredging to form a channel in which the bottom measures 23 ft below sea level took place in 1925.

Two tropical storms and one hurricane occurred during the period 1920-27 (U.S. Army Corps of Engineers, 1967). The hurricane of September 20, 1926, caused minor damage to coastal Alabama infrastructure, but did extensive damage to agricultural crops and timber.

The 1941 soundings database covers only the ebb-tidal delta of Mobile Bay. Figure 30 is the 1941 bathymetric map which shows that the ebb-flood tidal channel west and southwest of Morgan Peninsula has been partially

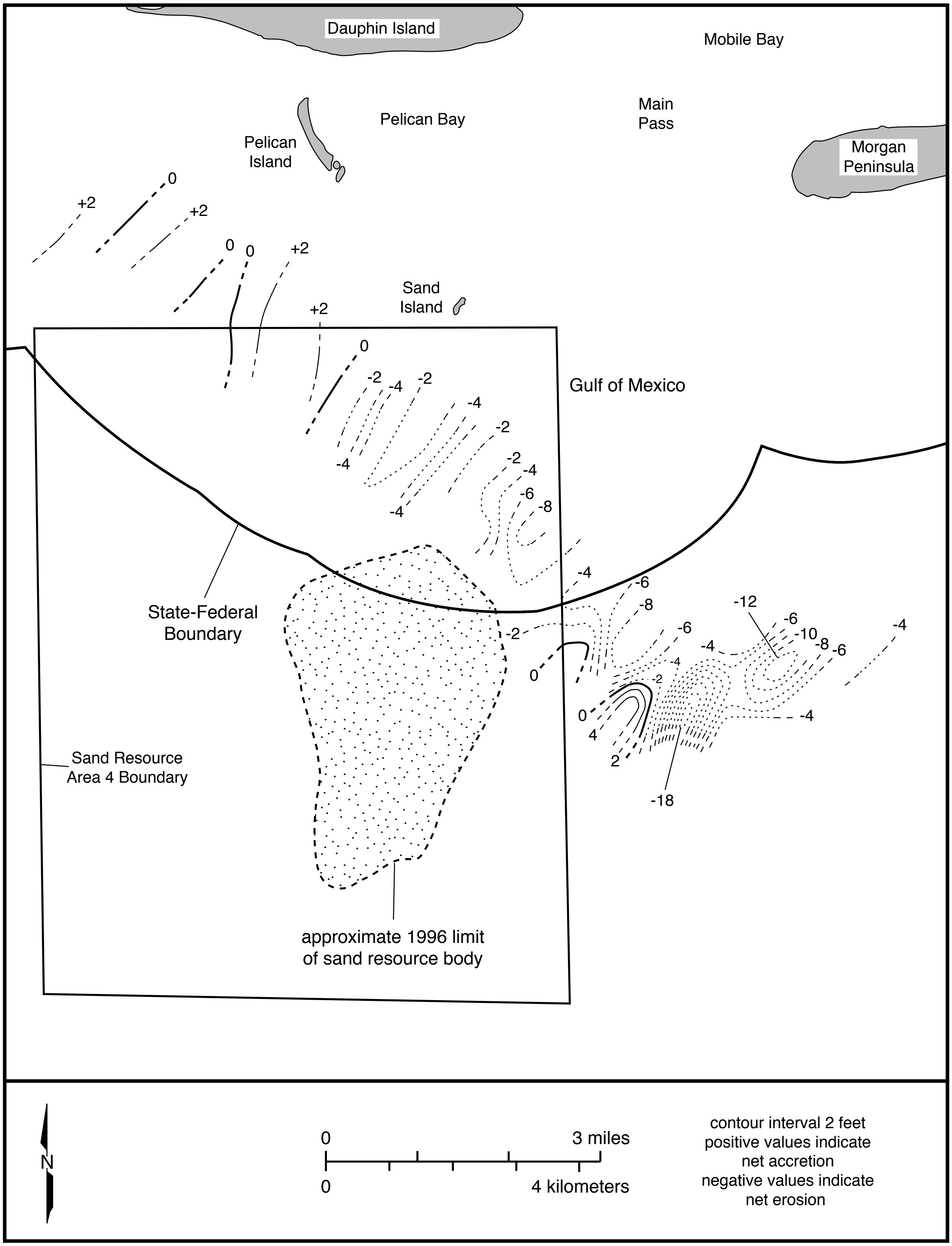


Figure 27.--Bathymetric differencing map of study area, 1918 to 1920.

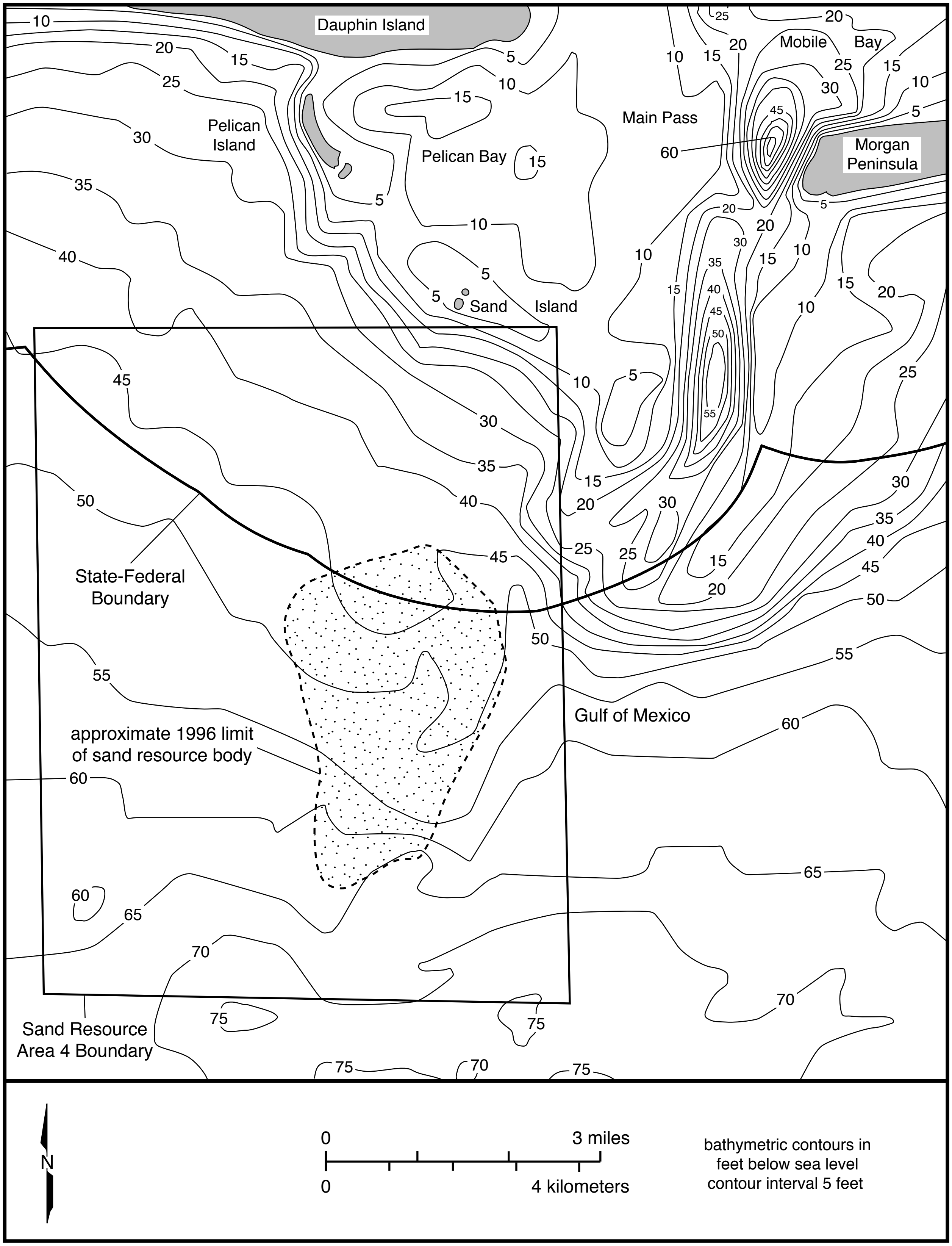


Figure 28.--Bathymetry of study area, 1927 (modified from U.S. Coast and Geodetic Survey, 1927).

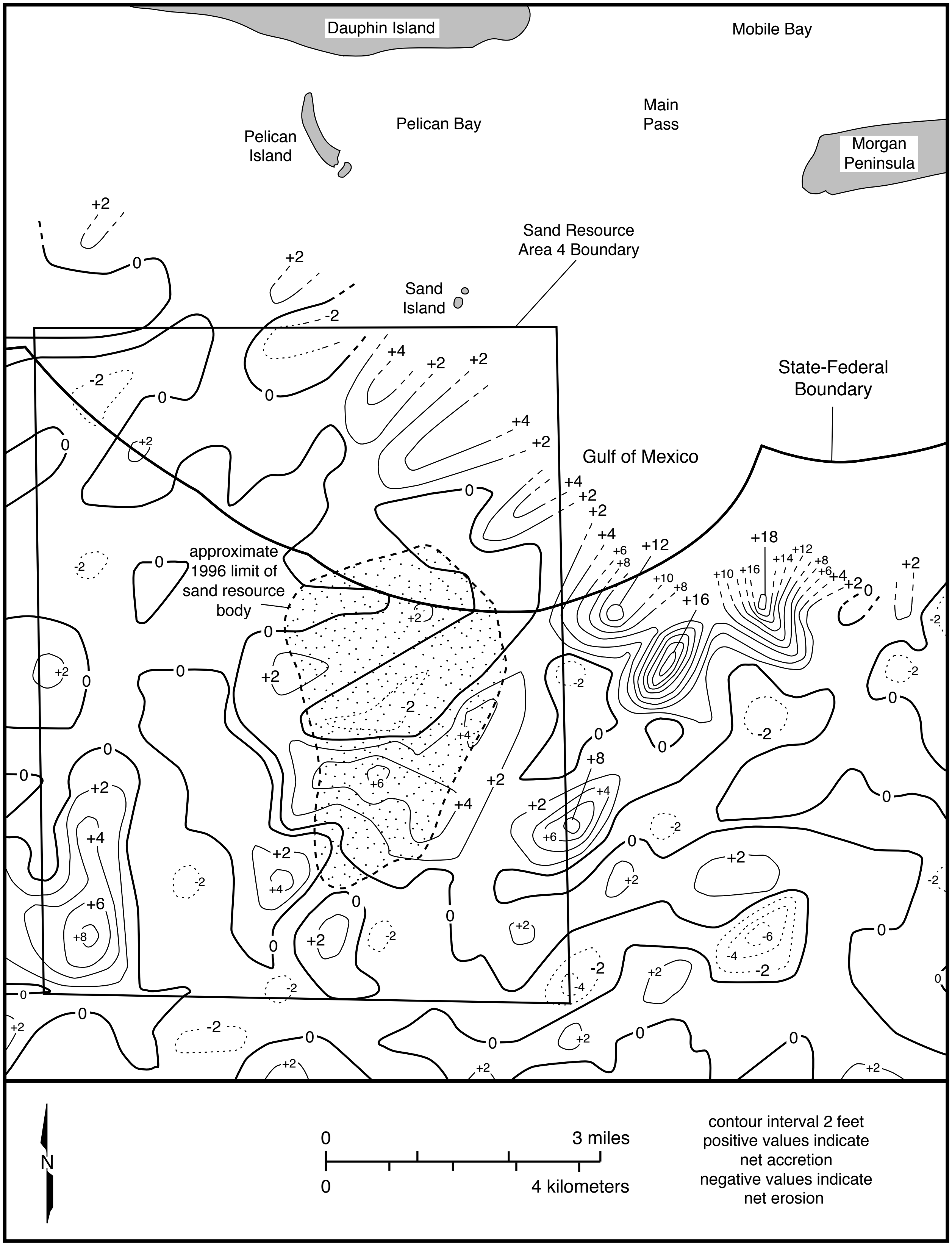


Figure 29.--Bathymetric differencing map of study area, 1920 to 1927.

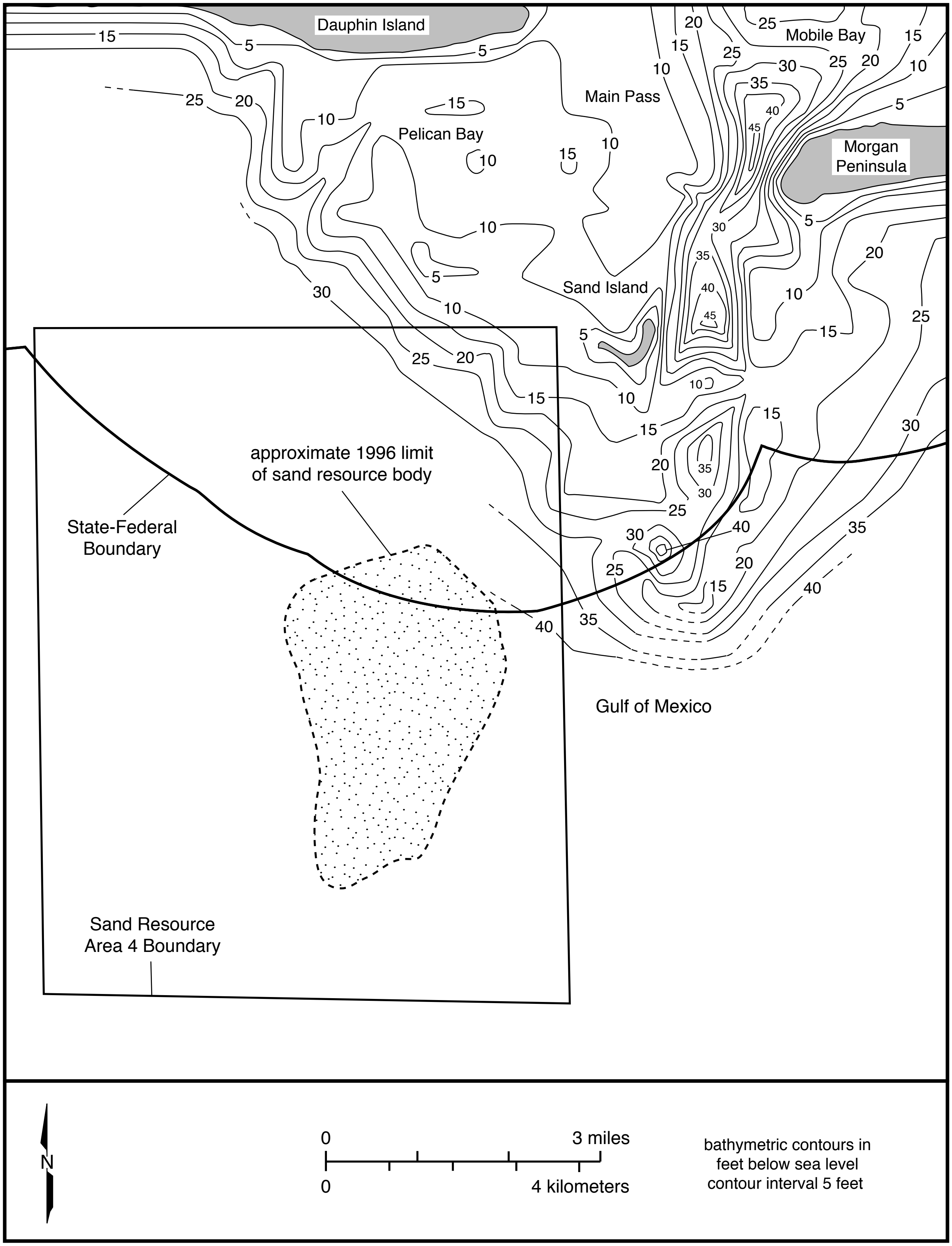


Figure 30.--Bathymetry of study area, 1941 (modified from U.S. Coast and Geodetic Survey, 1941).

infilled since 1927 (figs. 28, 30). The southern apex of the ebb-tidal delta of Mobile Bay, the location of the Mobile Bay entrance channel (south-southeast of Sand Island), was deepened during 1927-41 (figs. 28, 30). The U.S. Army Corps of Engineers dredged the entrance channel to 40 ft below sea level between 1927 and 1941. Pelican Island has disappeared, and Sand Island has grown into a crescent shape and is now located due west of the channel (fig. 30). The original hydrographic map for 1941 indicates that Dauphin Island is once more a continuous island as it is today (1997).

The 1927-41 bathymetric differencing map (fig. 31) shows the infilling of the channel with sediments derived from the surrounding continental shelf. Some shelf sedimentation has occurred south of the ebb-tidal delta of Mobile Bay and in the northwest portion of area 4 (fig. 31). Pelican Bay's water depth has not changed appreciatively, but the loss of Pelican Island shows up west of Pelican Bay. Without Pelican Island, Gulf of Mexico waves can cross Pelican Bay and impact of the shoreline of Dauphin Island, resulting in net erosion (fig. 31). Much of the sediment eroded from Dauphin and Pelican Islands has been deposited in the extreme northwest corner of the study area (fig. 31). The Morgan Peninsula littoral drift system appears to be depositing sediment in the channel, causing sediment starvation of Dauphin Island.

From 1927 to 1941, one hurricane and two tropical storms had affected the Alabama coast (U.S. Army Corps of Engineers, 1967). These storms inflicted minimal impact on coastal Alabama.

Figure 32 is a 1960 bathymetric map for the study area. Unfortunately, the soundings database covers only about a third of the study area. As can be seen, some ebb-flood tidal channel infilling has occurred north of the present-day State-Federal Boundary. Sand Island has grown into an elongate island. Area 4 has remained practically unchanged (figs. 30, 32). Dauphin Island is

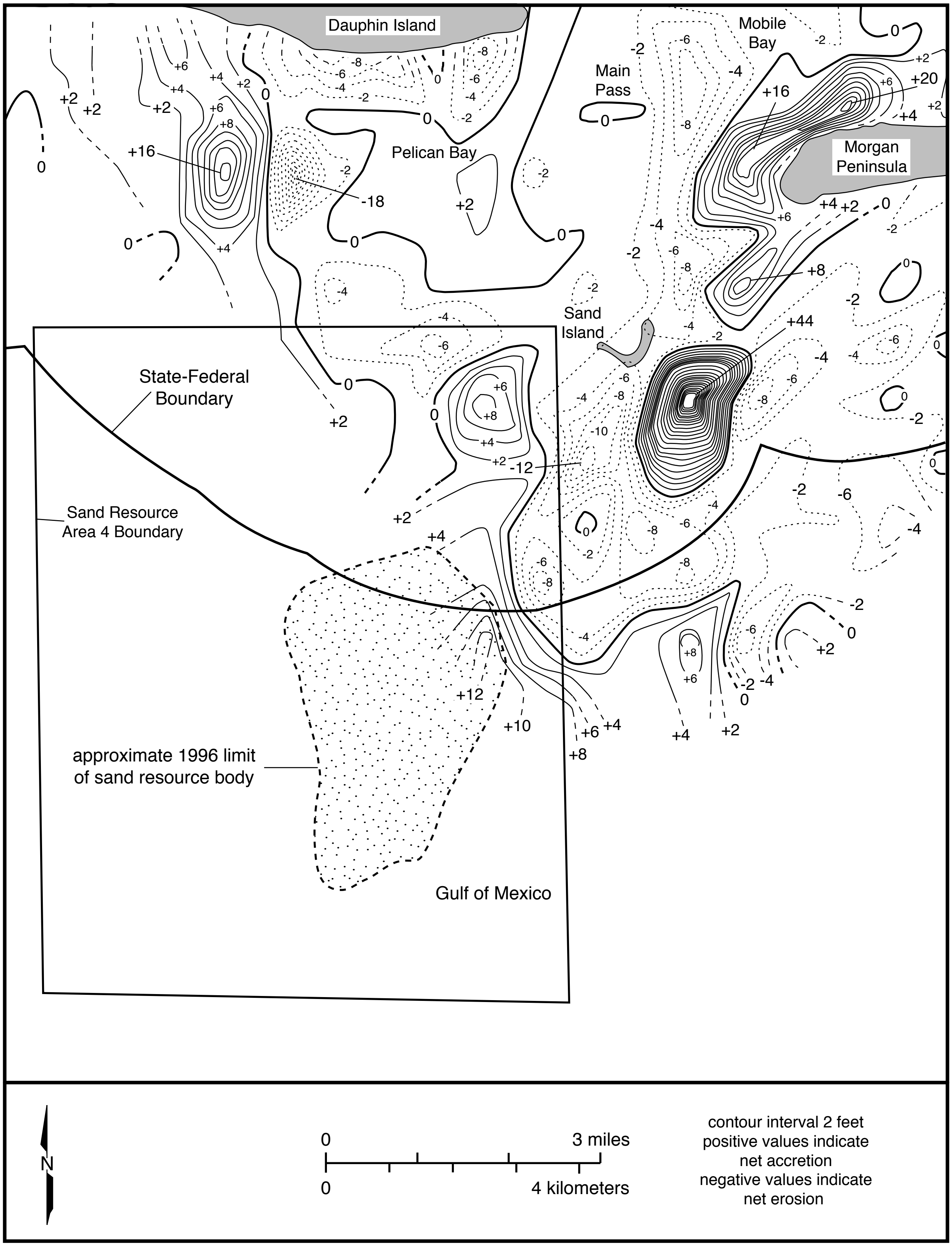


Figure 31.--Bathymetric differencing map of study area, 1927 to 1941.

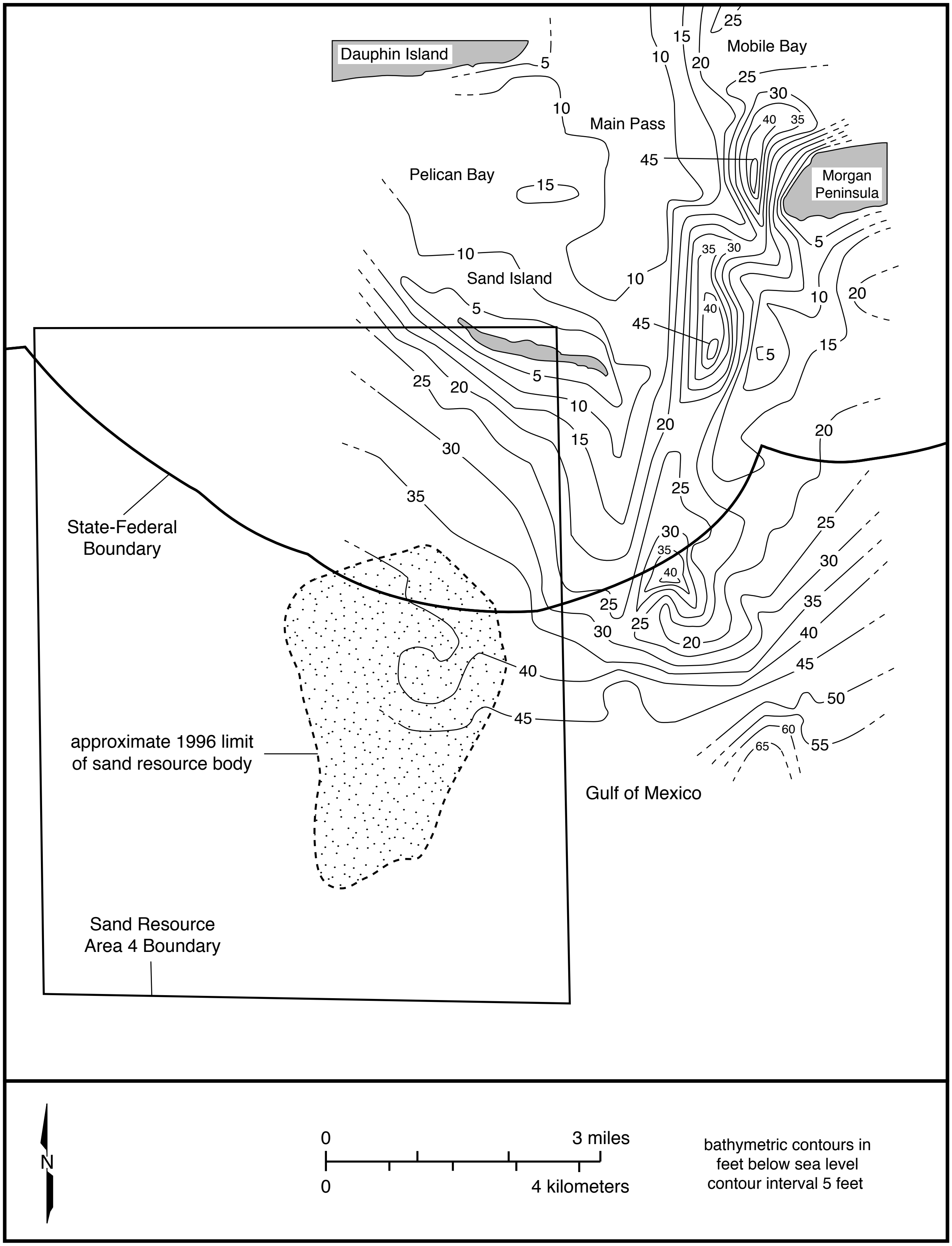


Figure 32.--Bathymetry of study area, 1960 (modified from U.S Coast and Geodetic Survey, 1960).

a continuous island as it was in 1941. The 1941-60 bathymetric differencing map (fig. 33) indicates that a portion of the channel has partially filled with sediment derived from the channel margins. The pattern of erosion and deposition indicates that the 1960 sediment transport pathways, dictated by the littoral drift system, appear to be unchanged from 1941. The Mobile Bay entrance channel through the apex of the ebb-tidal delta of Mobile Bay has maintained its deep of 40 ft.

During the period 1941-60, five hurricanes and three tropical storms affected coastal Alabama (U.S. Army Corps of Engineers, 1967). All inflicted minimal damage to the Alabama coast.

The 1969 bathymetric map shows that the configuration of the ebb-flood tidal channel has changed since 1960 (figs. 32, 34). The northern and southern ends of the channel have partially infilled, and the deepest portion of the southern end of the channel has shifted toward the north. Pelican Island has also moved north, and shows some growth at its northern end. The 1960 and 1969 bathymetric data indicates that area 4 has deepened during this time period. In 1969, Dauphin Island is in its unbreached state, as it appears today (1997).

The bathymetric differencing map for 1960-69 (fig. 35) shows that erosion has taken place during this time in area 4. In addition, sediment deposition has occurred in the northern and southern ends of the ebb-flood tidal channel, while erosion is associated with the migration of the deepest portion of the southern end of the channel. Pelican Bay and Main Pass both have partly filled with sediments during 1960-69. The primary nearshore sediment pathway appears to be from Morgan Peninsula across the channel, and through Pelican Bay to Dauphin Island. However, some sediment moves from Morgan Peninsula,

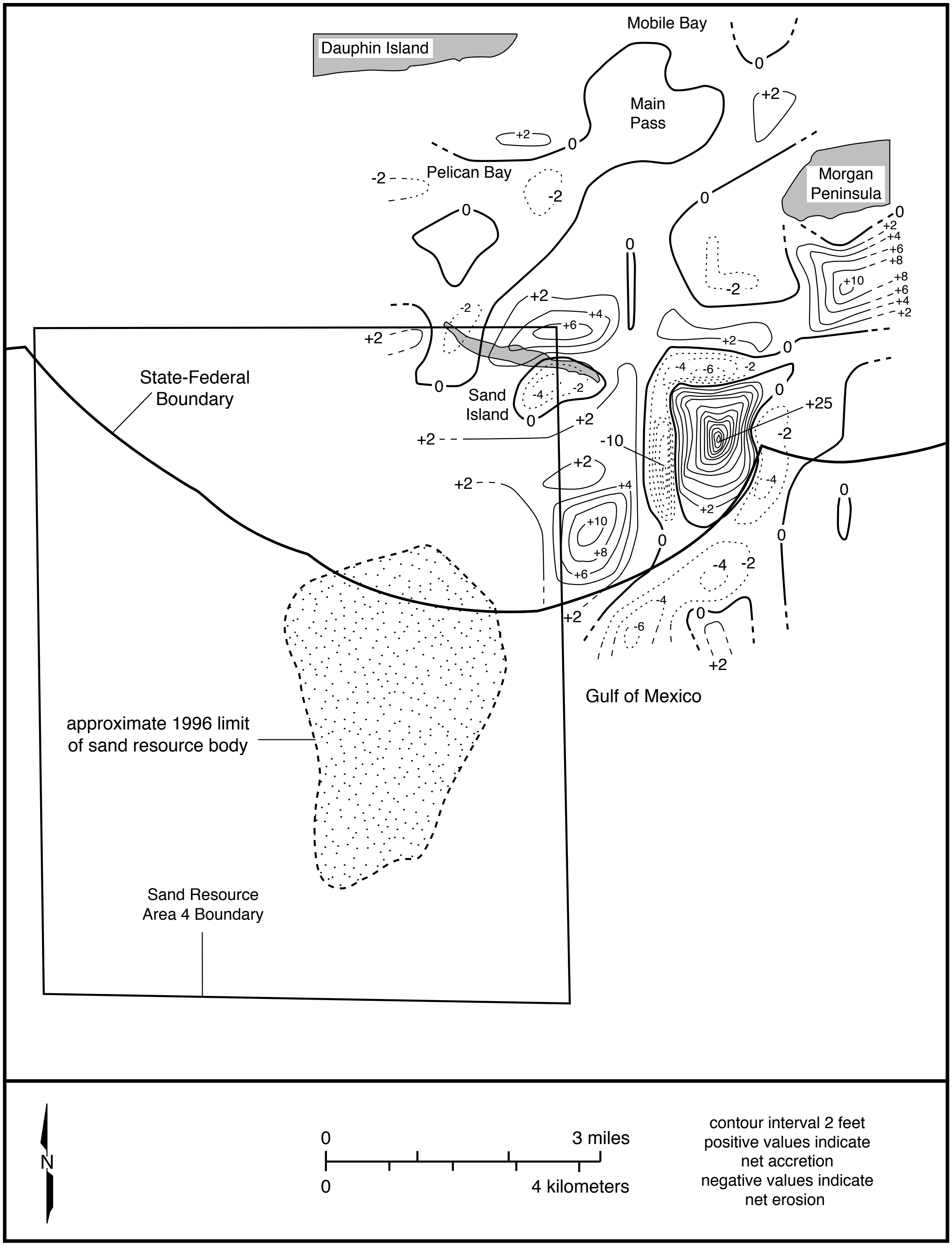


Figure 33.--Bathymetric differencing map of study area, 1941 to 1960.

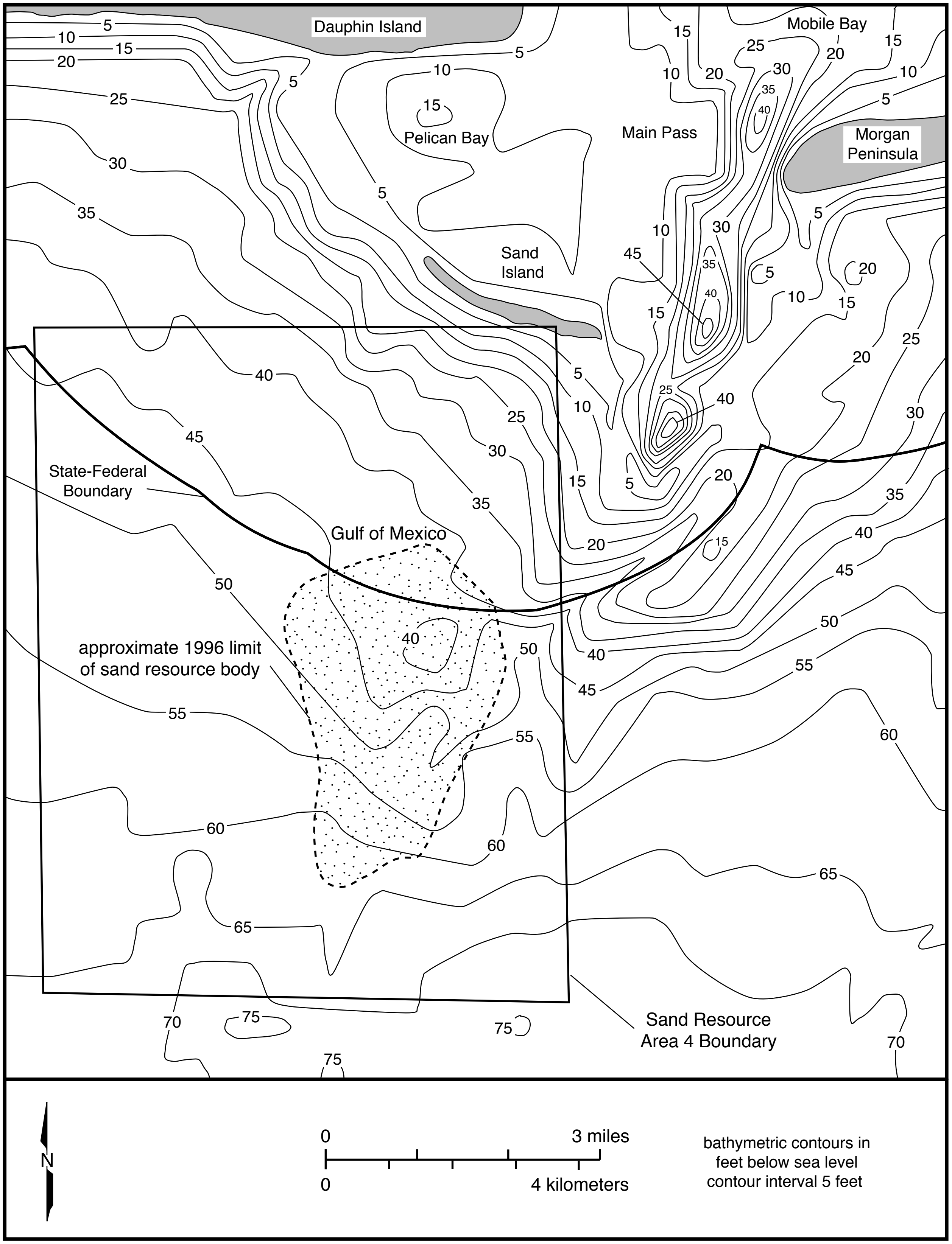


Figure 34.--Bathymetry of study area, 1969 (modified from U.S. Coast and Geodetic Survey, 1969).

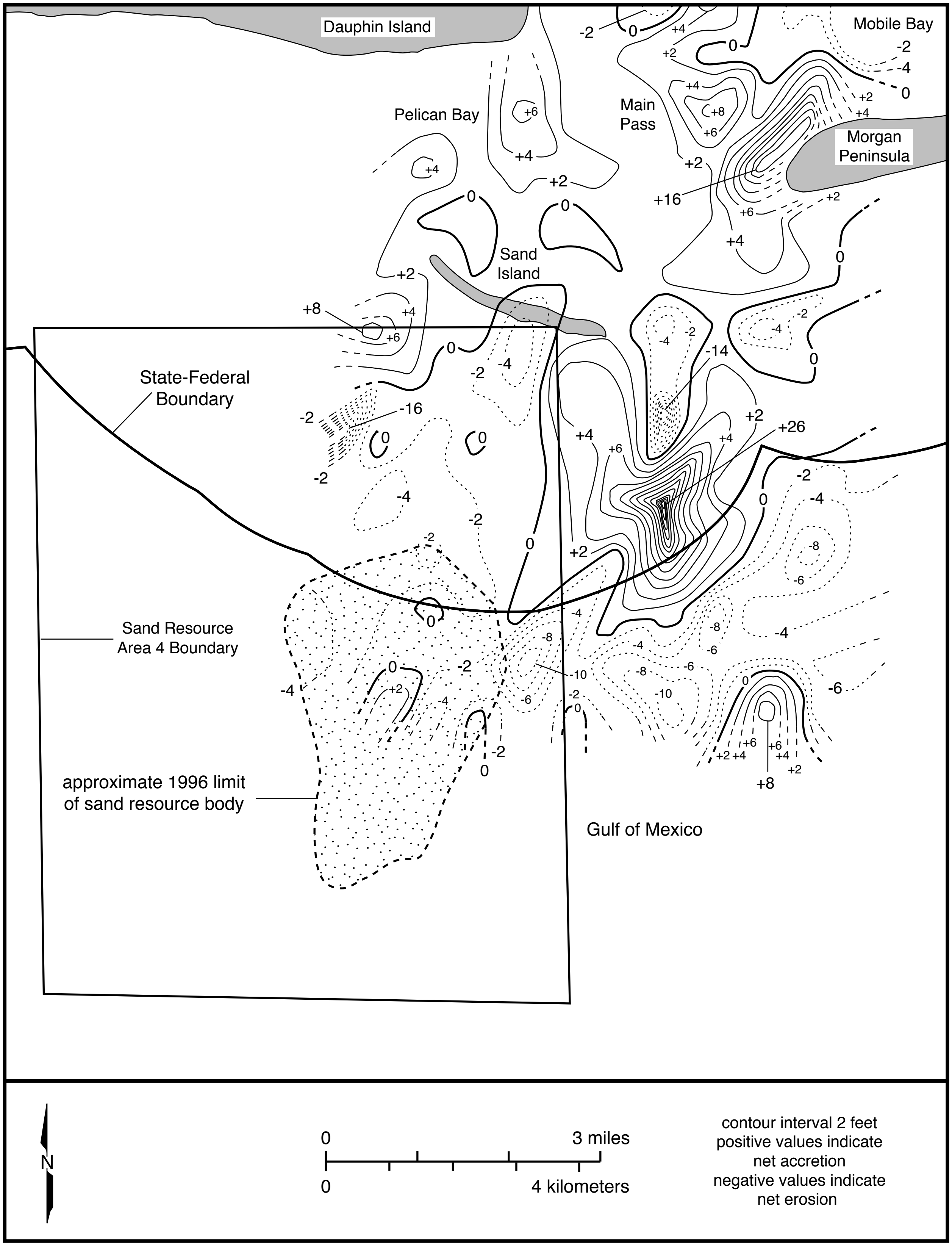


Figure 35.--Bathymetric differencing map of study area, 1960 to 1969.

southeastward, around the southern margin of the ebb-tidal delta of Mobile Bay, then along Sand Island, and northerly to Dauphin Island.

Between 1960 and 1969, one hurricane affected coastal Alabama (U.S. Army Corps of Engineers, 1967). Hurricane Hilda, October 3, 1964, inflicted minimal damage to the Alabama coast. However, a cold front associated with the passage of Hilda caused more damage to coastal Alabama than the hurricane. Still, the damage caused by the cold front was minimal.

Figure 36 is a 1977 bathymetric map of the study area. The map shows that the ebb-flood tidal channel has returned to the 1960 configuration (figs. 32, 36). Sand and Pelican Islands are absent in 1977, and area 4 is virtually unchanged. Dauphin Island is a continuous island as it appears today (1997).

The 1969-77 bathymetric differencing map (fig. 37) shows evidence of the fact that the ebb-flood tidal channel was dredged, or perhaps scoured by Hurricane Camille (August 17, 1969). The dredged Mobile Bay Ship Channel can be seen north of Main Pass, flanked by disposed dredged material (fig. 37). The channel through the ebb-tidal delta of Mobile Bay, east and southeast of Morgan Peninsula, shows dredging over much of its length. The string of centers of sediment deposition that stretch out in a northeast-southwest direction on both sides of the channel and extend offshore to the southeast corner of area 4, are not dredged material disposal piles (fig. 37). Instead, the piles indicate sediment transport from Morgan Peninsula along the eastern margin of the ebb-tidal delta of Mobile Bay due to the presence of the channel. Some sediment is transported northwestward along the western margin of the ebb-tidal delta of Mobile Bay, and on to Dauphin Island (fig. 37). Nearshore Dauphin Island positive contours indicates that the beaches of the southeastern shoreline of Dauphin Island were in an accretionary state. In the absence of Pelican and Sand Islands, tidal channels formed through Pelican Bay,

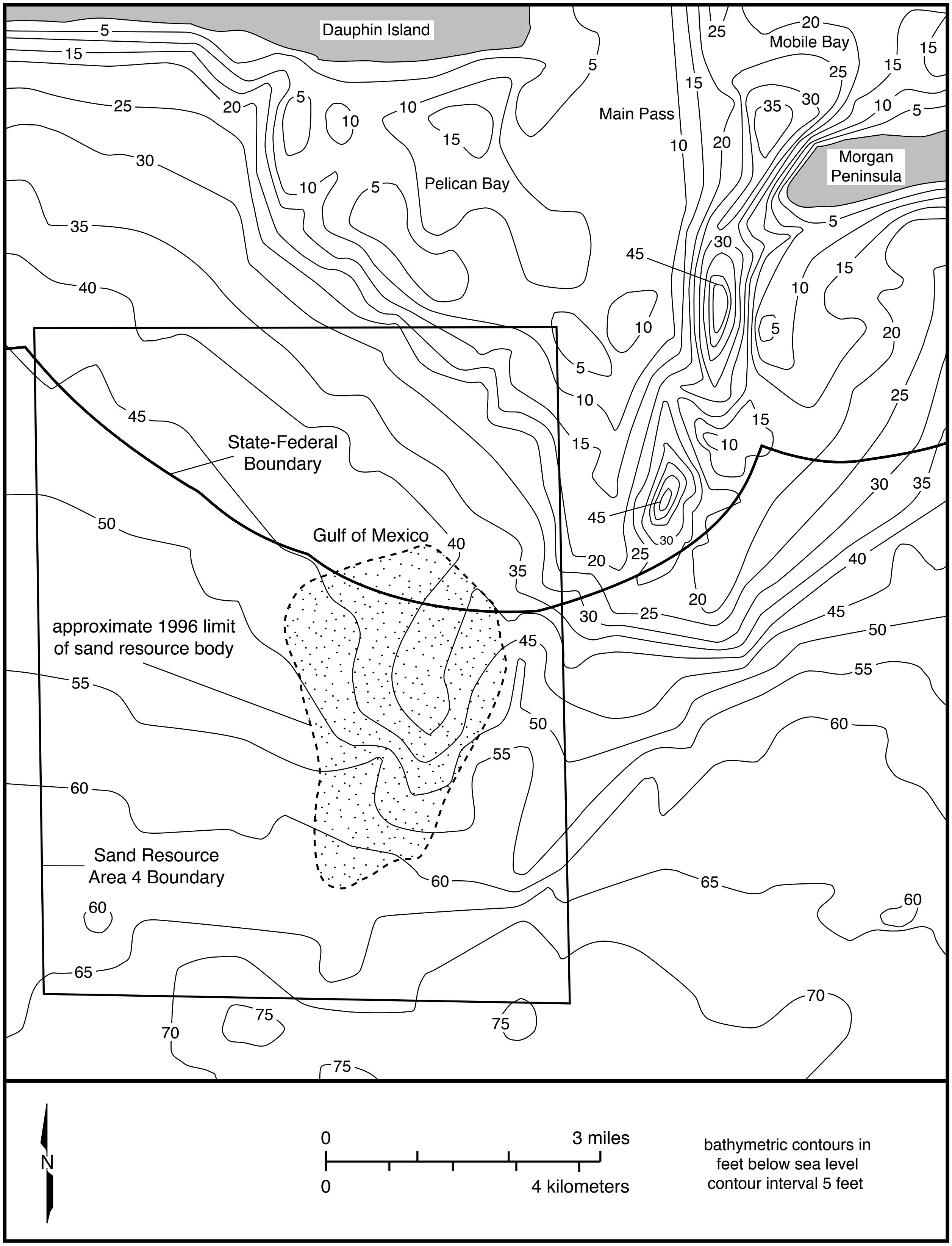


Figure 36.--Bathymetry of study area, 1977 (modified from National Oceanic and Atmospheric Administration, 1977).

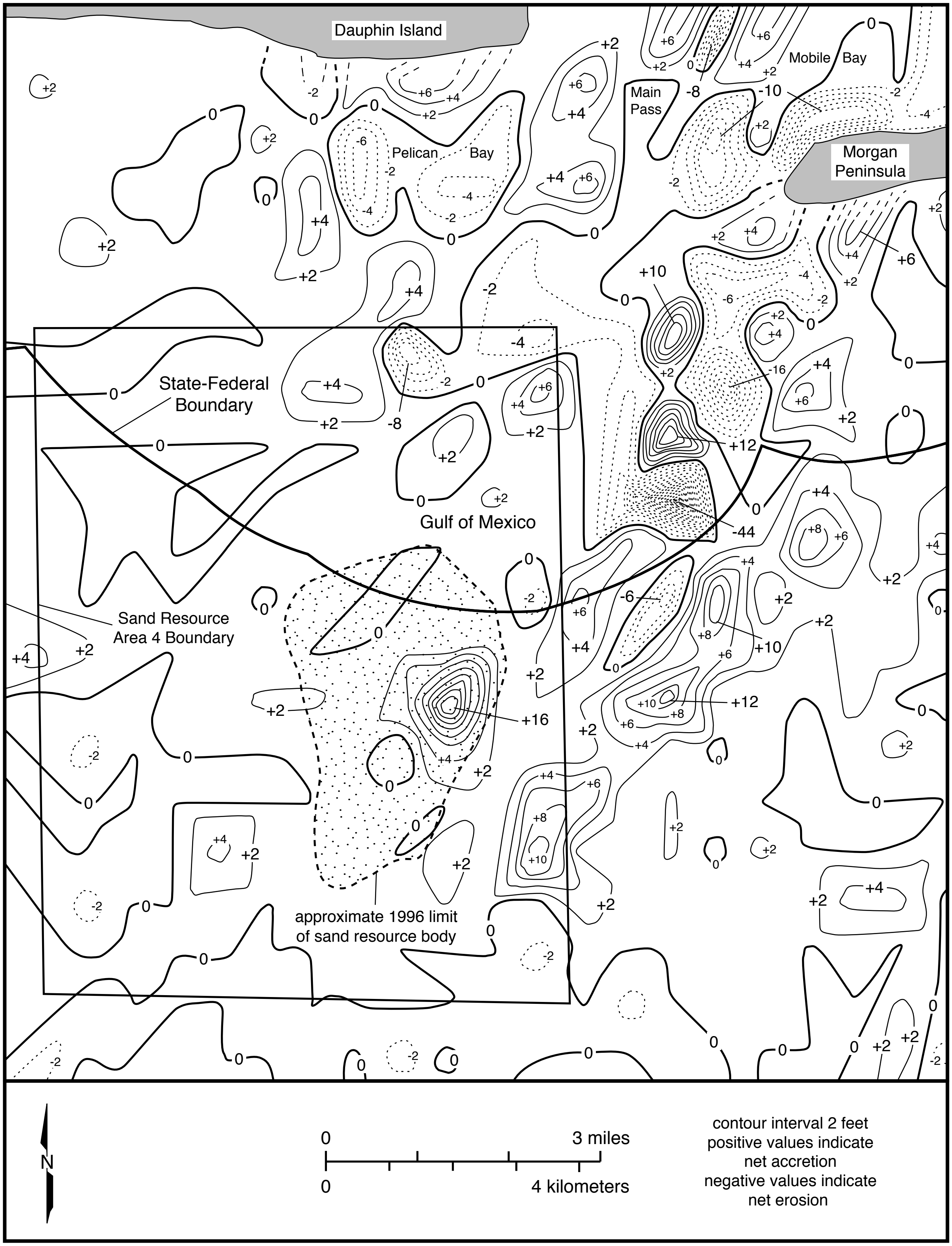


Figure 37.--Bathymetric differencing map of study area, 1969 to 1977.

connecting Mobile Bay with the open Gulf of Mexico (fig. 36). These tidal channels appear as the deepened portions of Pelican Bay on figure 37, and are reflected in the bathymetric contours of figure 36. Area 4 has not changed during the period 1969-77, except for accretion at several locations in the eastern third of the area (fig. 37).

Three hurricanes occurred during the period 1969-77 that affected the Alabama coast (Chermock, 1976). Hurricane Camille, August 17, 1969, is considered one of the most destructive hurricanes to strike the northern Gulf of Mexico. Landfall of the hurricane was at Waveland, Mississippi, about 80 mi east-southeast of Mobile, Alabama. High winds and storm surge caused minimal to moderate damage to coastal Alabama. Hurricanes Agnes (June 12, 1972) and Eloise (September 23, 1975) principally affected panhandle Florida and caused minimal damage to the Alabama coast.

A 1987 bathymetric map is presented as figure 38. The configuration and placement of the ebb-flood tidal channel through the ebb-tidal delta of Mobile Bay has not changed from 1977-87 (figs. 36, 38). However, the channel appears shallower, especially the southern two-thirds (fig. 38). Pelican and Sand Islands have appeared on the 1987 bathymetric map as a series of five islands (fig. 38). Area 4 is unchanged from 1977, except for sediment accretion on northern end of the 1996 sand resource body. Dauphin Island is one continuous island as it is today (1997).

The 1977-87 bathymetric differencing map of the study area (fig. 39) shows the partial infilling of the ebb-flood tidal channel with sediment derived by erosion of the surrounding sea floor. In addition, deposition of sediments in the northeast quarter of area 4 can be seen on the map (fig. 39). Both deposition and erosion has taken place in Pelican Bay. Littoral drift transported sediments from Morgan Peninsula and Mobile Bay move into the channel, and appear to

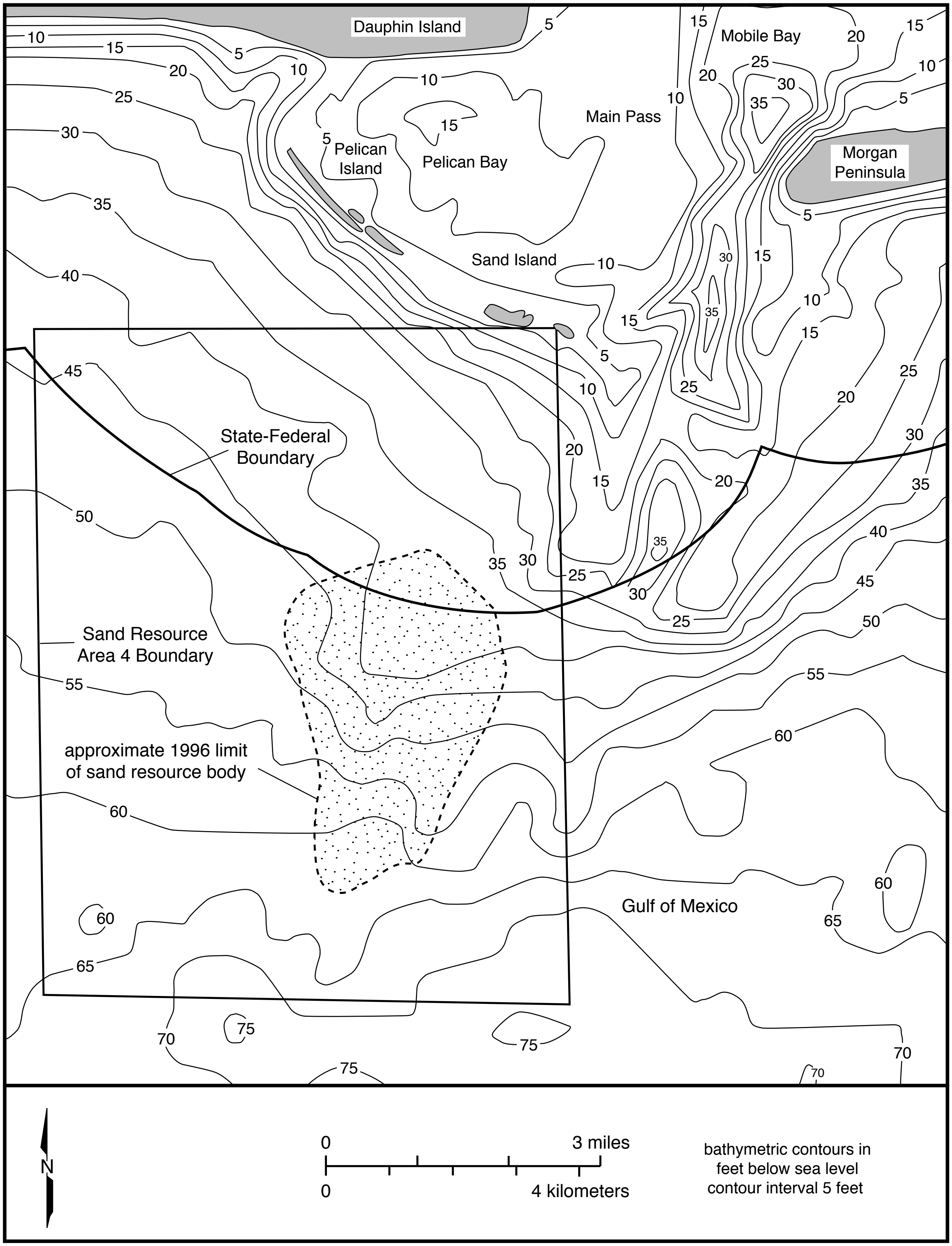


Figure 38.--Bathymetry of study area, 1987 (modified from National Oceanic and Atmospheric Administration, 1987).

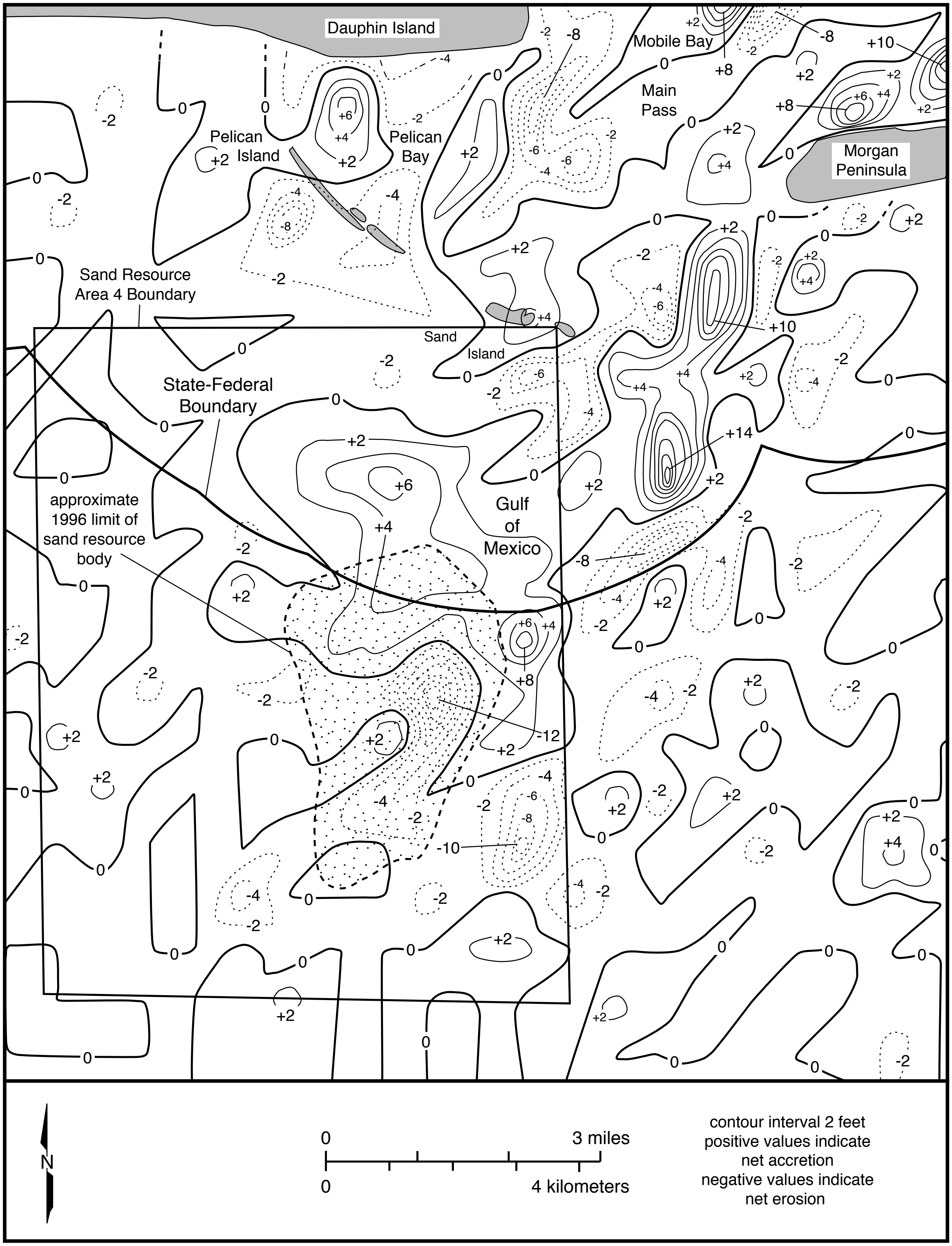


Figure 39.--Bathymetric differencing map of study area, 1977 to 1987.

be flushed out of the channel by tidal currents, to form a sediment apron in northeast area 4 (fig. 39). Pelican Bay and vicinity is in an erosive state, probably due to the limited supply of sediments from Morgan Peninsula. Gulf of Mexico waves impinging on the western margin of the ebb-tidal delta of Mobile Bay, and lack of sediment supply, has sculpted Pelican Island into thin, elongate islands (fig. 39). The waves have also steeped the shoreface by eroding the western margin of the ebb-tidal delta of Mobile Bay (compressed isobaths on figure 38). The pass between Pelican and Dauphin Islands allows tidal exchange between Mobile Bay and the open Gulf of Mexico (fig. 39). Gulf of Mexico waves refracted around the northern tip of Pelican Island, impinge on the Dauphin Island shoreline north of Pelican Island (fig. 38). Sediments eroded from Dauphin Island appear to be shallowing and narrowing the pass by sediment deposition inside the pass in northwestern Pelican Bay (fig. 39). The sediments are also used by the hydrographic system to lengthen Pelican Island by accretion at its northern end. The narrowed nearshore Dauphin Island bathymetry on figure 38, and negative valued contours in the same area on figure 39, indicate the presence of an erosive state along the Dauphin Island shoreline. The shoreline erosion is primarily caused by tidal currents flowing through the pass. Some of the sediment eroded from Dauphin Island is transported westward down the Dauphin Island shoreline by the littoral drift.

From 1977-87, two hurricanes had affected the Alabama coast, Frederic (September 12, 1979), and Elena (September 2, 1985) (U.S. Army Corps of Engineers, 1981, 1987). Overall, hurricane Elena inflicted minimal damage to coastal Alabama. Dauphin Island was the hardest hit area. Wind and storm surge caused minimal to moderate damage on the Island.

Hurricane Frederic, a category 3 hurricane (table 1), made landfall at the western end of Dauphin Island with winds estimated at 130 mph, gusting to 155 mph (U.S. Army Corps of Engineers, 1981). The combination of high winds and a storm surge of 10-15 ft caused extensive damage to Mobile and Baldwin Counties, the hardest hit area on the Gulf of Mexico. Dredging of the Mobile Bay entrance channel was required after the hurricane (U.S. Army Corps of Engineers, 1981).

Figure 40 shows the 1997 bathymetric map of the study area. The southern end of the ebb-flood tidal channel has been deepened by dredging (figs. 38, 40). Sand Island has diminished or disappeared, while Pelican Island has lengthened by accretionary growth at its northern end and developed a crescent shape (fig. 40). Area 4 has shallowed overall, and the nearshore berm (one of two built by the U.S. Army Corps of Engineers in 1986 to study the movement of dredged material deposited in the federal dredged material disposal area) shows on the bathymetry near the center of area 4 (fig. 40). The pass between Dauphin and Pelican Islands has narrowed and deepened.

The 1987-97 bathymetric differencing map shows widespread accretion in the study area exclusive of the ebb-tidal delta of Mobile Bay (fig. 41). Littoral drift moves sediment from Morgan Peninsula southward along the eastern margin of the ebb-flood tidal channel to the southern apex of the ebb-tidal delta of Mobile Bay. Some sediment is deposited in the extreme northeastern corner of area 4, but it is not apparent how the littoral drift system moves sediment around the apex and toward Dauphin Island. It appears that much of the sediment used to accrete the northern end of Pelican Island comes from the destruction of Sand Island and the southern end of Pelican Island (fig. 41). Dauphin Island nearshore negative contours (fig. 41) and closely spaced bathymetry (fig. 40) indicate severe erosion caused by tidal currents moving through the pass between Pelican and Dauphin Islands. Pelican Bay shows

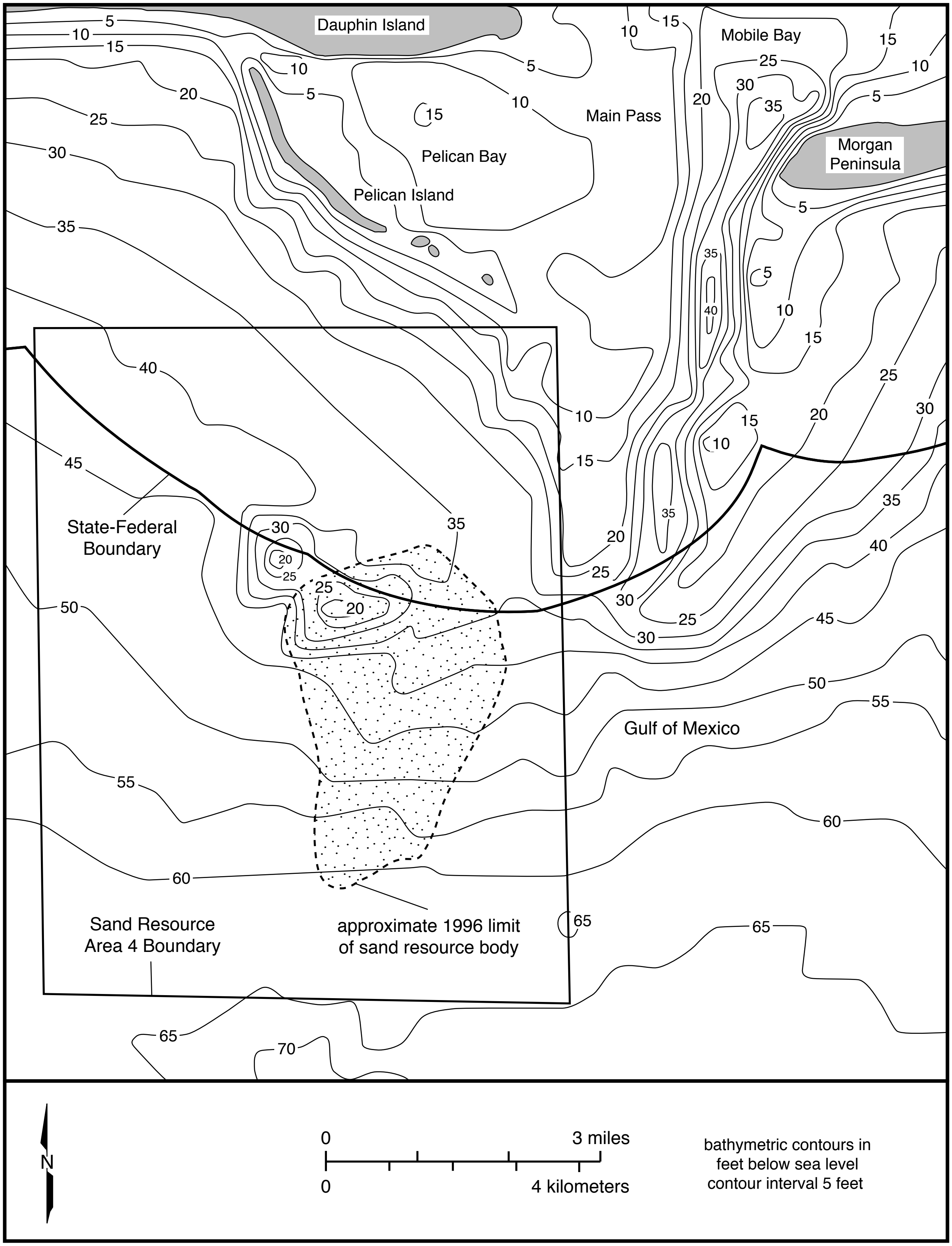


Figure 40.--Bathymetry of study area, 1997 (modified from National Oceanic and Atmospheric Administration, 1997).

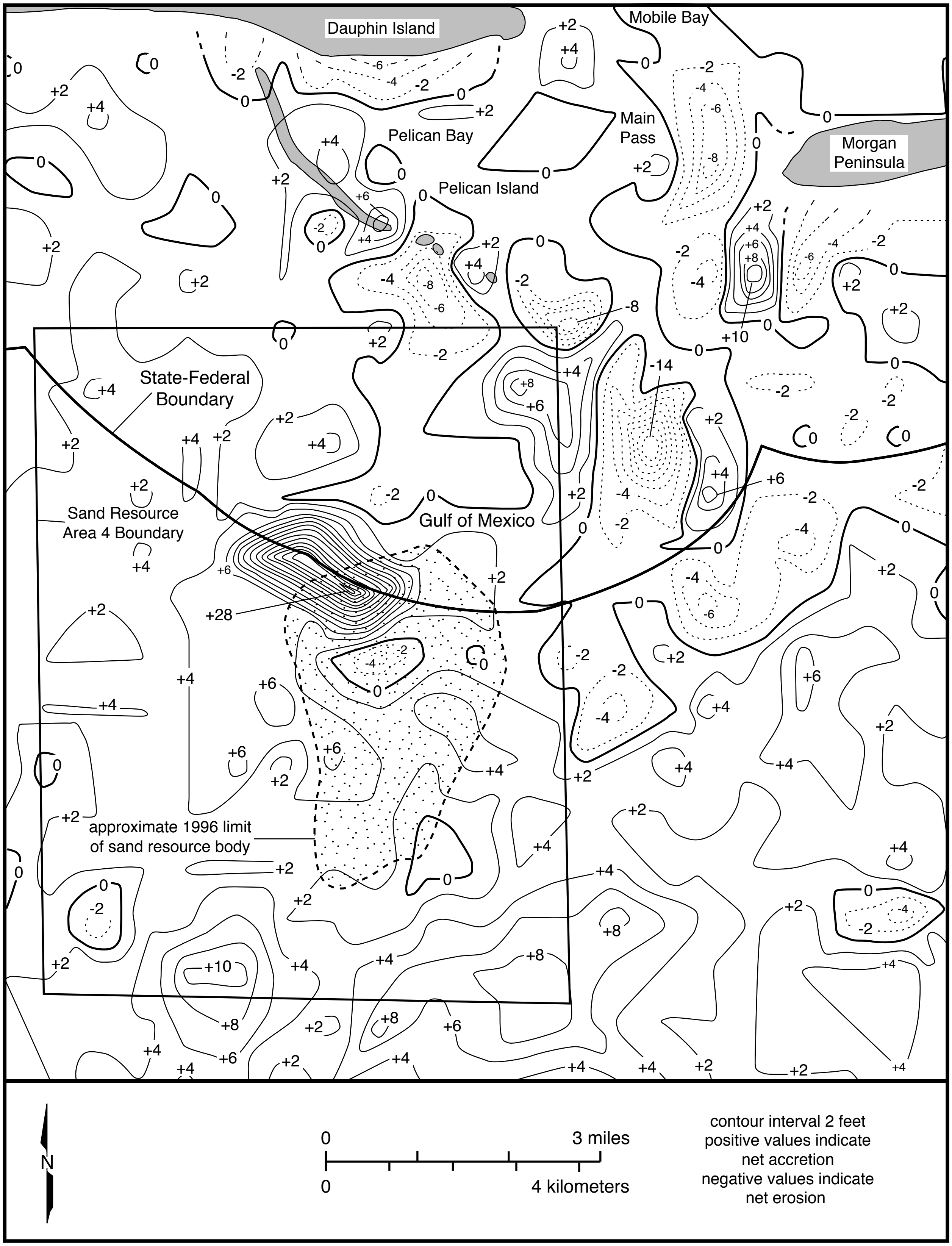


Figure 41.--Bathymetric differencing map of study area, 1987 to 1997.

very little change from 1987 to 1997. Some of the sediment eroded from the Dauphin Island shoreline is transported westward by littoral drift.

Two hurricanes, Opal (October 4, 1995) and Danny (July 18, 1997) affected coastal Alabama between 1987 and 1997. Overall, both hurricanes inflicted minimal damage to the Alabama coast. However, Hurricane Danny caused localized moderate beach and coastal dune erosion on the Dauphin Island Gulf of Mexico shoreline, and along the Morgan Peninsula Gulf of Mexico shoreline at Gulf Shores and Romar Beach.

SUMMARY OF BATHYMETRIC AND BATHYMETRIC DIFFERENCED MAPS

The bathymetric and bathymetric differencing maps, and historic illustrations and documents, chronicle a cycle of geographical and bathymetric change that has occurred over the past 294-year history of the study area. The interplay between coastal geography, bathymetry, and channel dredging, punctuated by hurricanes and tropical storms, dictates nearshore sediment transport pathways, Gulf of Mexico wave orientation, shoreline erosion and accretion, and tidal current velocity. Except for brief periods of erosion or deposition that caused bathymetric changes of a few feet, the overall bathymetry of area 4 has not changed appreciatively over the past 264 years.

This interplay and cycle of change in the study area is illustrated in figures 42, 43, 44, and 45, which show postulated nearshore sediment transport pathways.

From 1702-17, Pelican and Dauphin Islands formed a natural anchorage for ocean-going ships of the time, to offload cargo bound for Mobile at the Port of Dauphin Island. Sediment transport from Morgan Peninsula to Dauphin

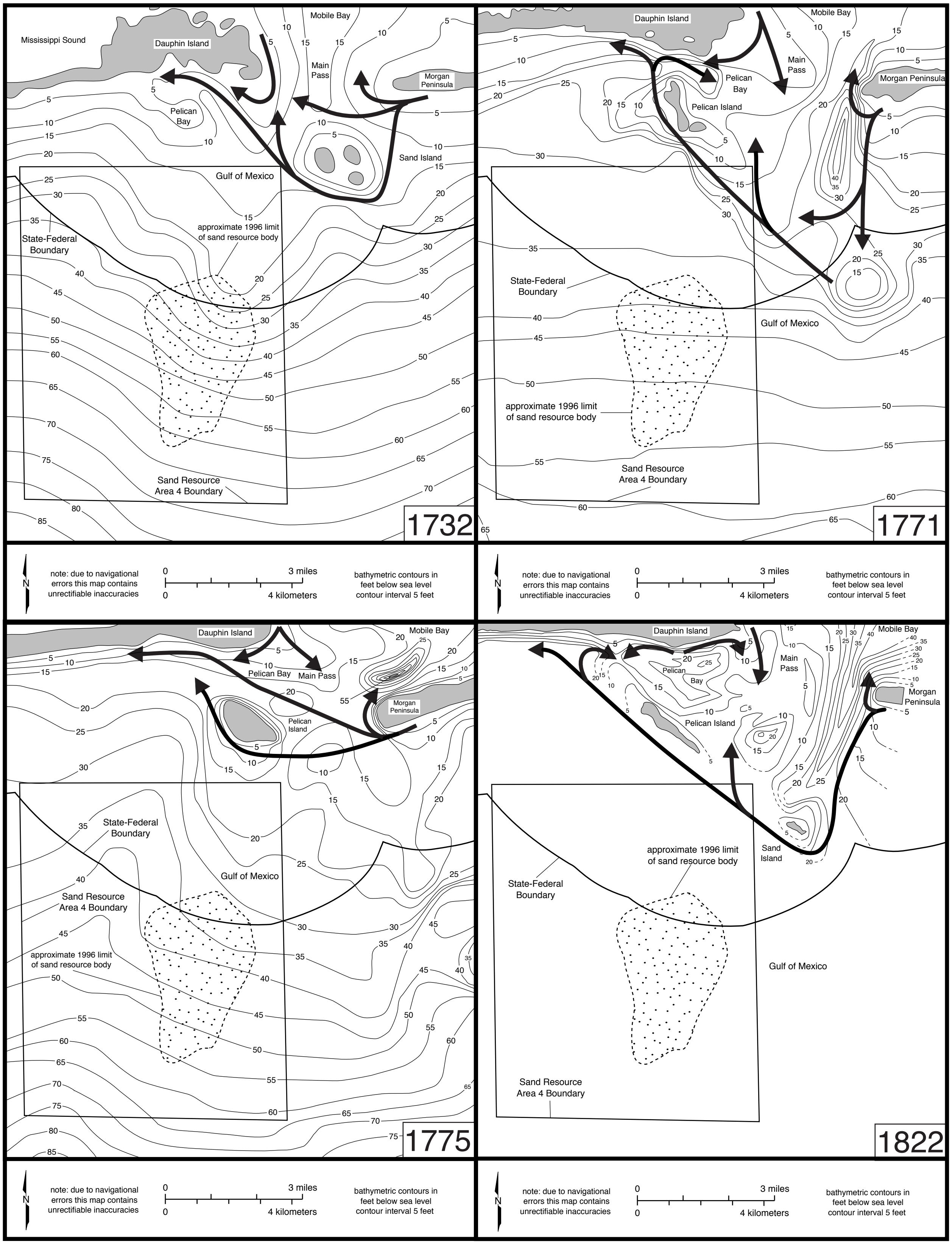


Figure 42.--Postulated nearshore sediment transport pathways (heavy arrowed lines) for 1732, 1771, 1775, and 1822.

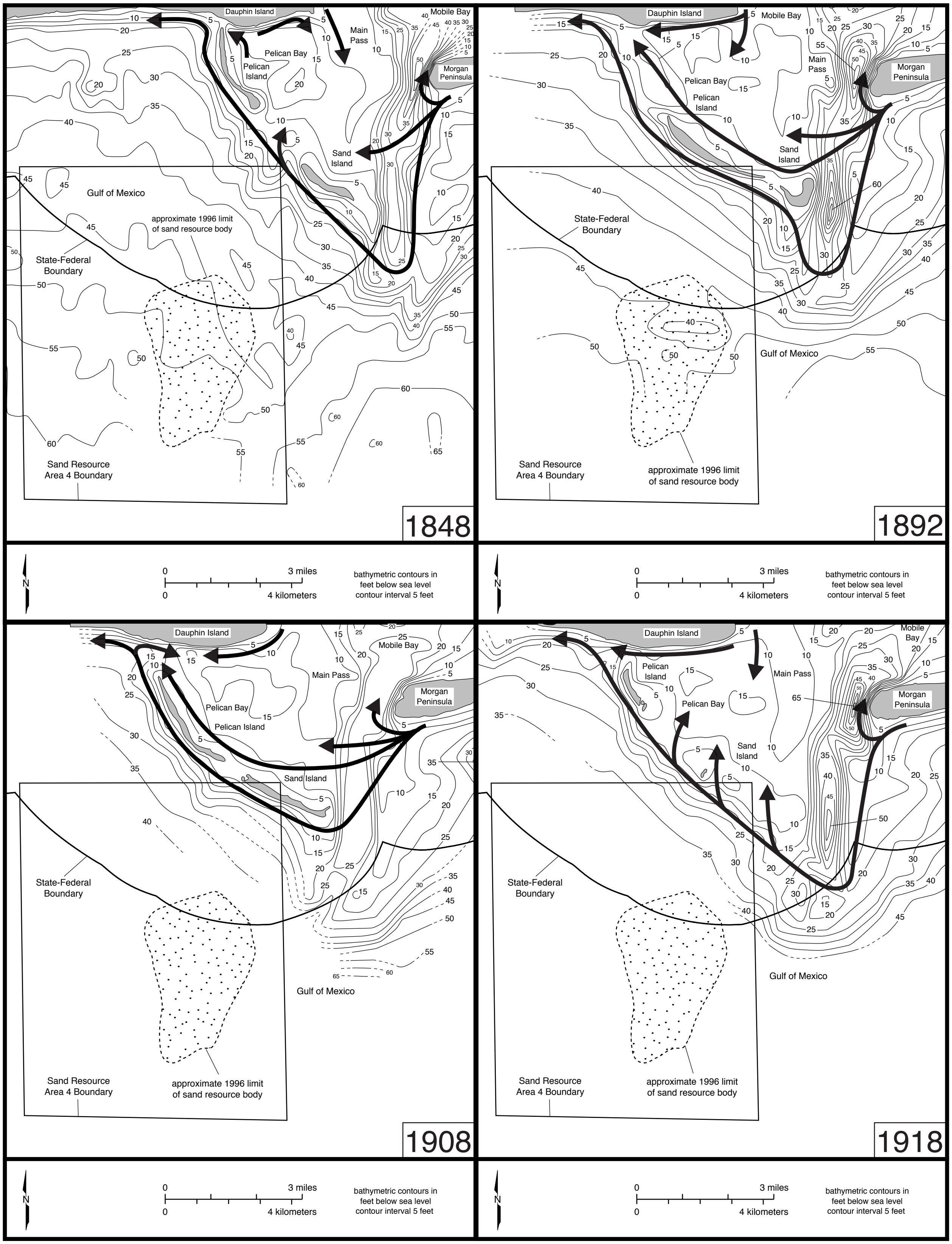


Figure 43.--Postulated nearshore sediment transport pathways (heavy arrowed lines) for 1848, 1892, 1908, and 1918.

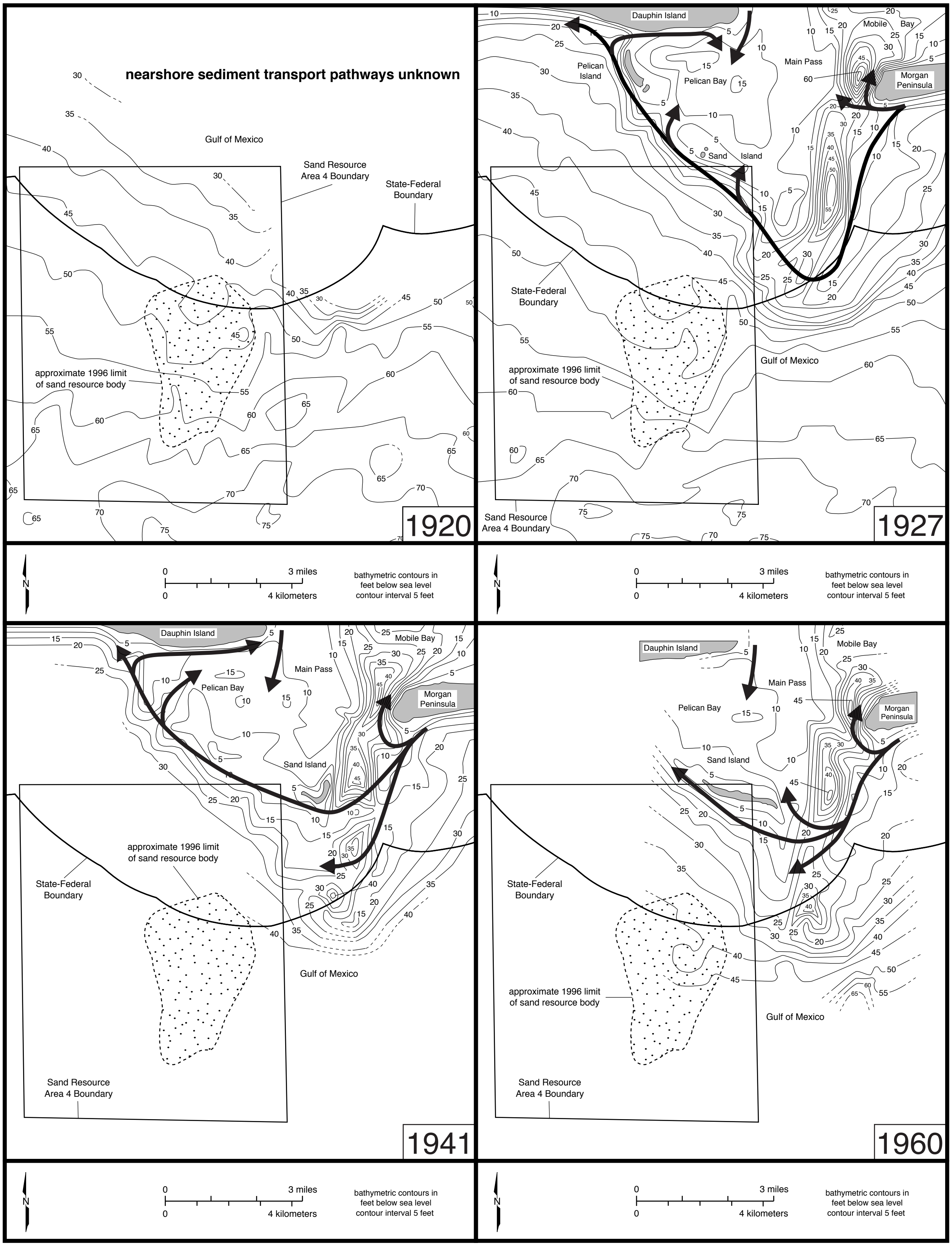


Figure 44.--Postulated nearshore sediment transport pathways (heavy arrowed lines) for 1920, 1927, 1941, and 1960.

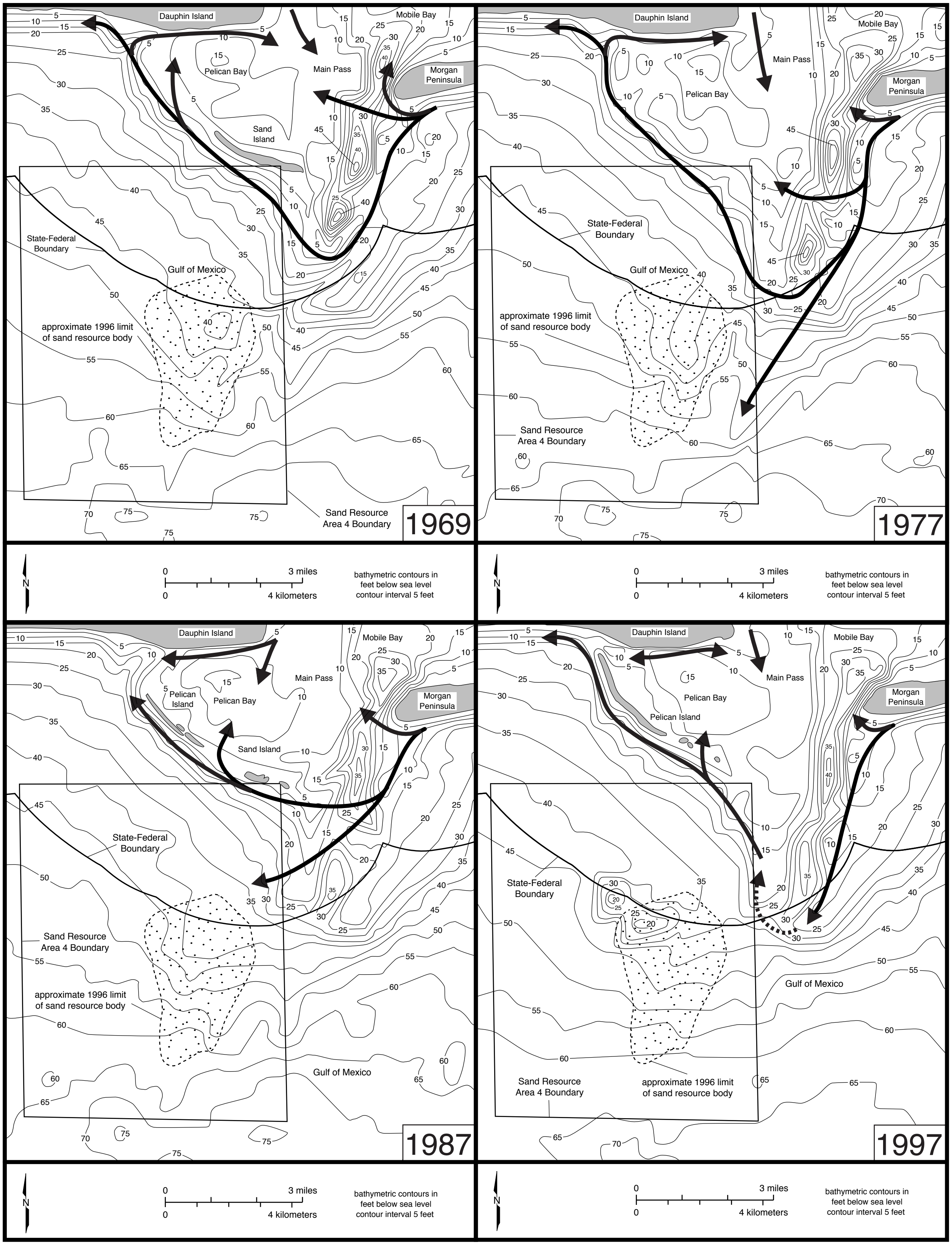


Figure 45.--Postulated nearshore sediment transport pathways (heavy arrowed lines) for 1969, 1977, 1987, and 1997.

Island was probably along the western shoreline of Pelican Island and also westward from Morgan Peninsula to Dauphin Island. A storm in May 1717 closed the port by sediment deposition in the entrance to the coastal embayment contained in the Dauphin Island shoreline.

By 1732, Pelican Island disappeared, perhaps due to a hurricane (fig. 42). Bathymetry, absence of Pelican Island, and shallowness of Main Pass indicate that nearshore sediment transport pathways in 1732 were probably around the cluster of islands that represent Sand Island. Between 1732 and 1997, flood and ebb tidal currents contributed to sediment transport around the west end of Morgan Peninsula and the east end of Dauphin Island, respectively (figs. 42, 43, 44, 45).

The hurricane of September 12, 1740, probably scoured the ebb-flood tidal channel west of Morgan Peninsula that appears on the 1771 bathymetric map (fig. 42). In addition, the hurricane breached Dauphin Island. This channel impeded sediment transport from Morgan Peninsula, westward to Dauphin Island. The main sediment transport pathway in 1771 was south and then northwestward along the western margin of the ebb-tidal delta of Mobile Bay to Dauphin Island (fig. 42). In the process, Pelican Island formed and grew by accretion at its northern end. The close proximity between Dauphin and Pelican Islands restricted ebb-tidal flow between the Islands and resulted in high tidal current velocity, deepening Pelican Bay. Wave energy is focused by the acute angle formed by Dauphin and Pelican Islands, resulting in erosion of the southeastern shoreline of Dauphin Island.

The hurricane of September 4, 1772, may have caused the migration of the ebb-flood tidal channel into Mobile Bay, which allowed sediment transport to proceed westward once again from Morgan Peninsula to Dauphin Island by 1775 (fig. 42). The influx of sediment into Pelican Bay caused the shallowing and southeastward expansion of the ebb-tidal delta of Mobile Bay. The southeastern Dauphin Island shoreline was probably accretionary in 1775.

The southward extension of the ebb-flood tidal channel in 1822, perhaps a result of the hurricane of 1822, caused sediment transport along Morgan Peninsula to be directed toward the southeast, and then northwestward along the western edge of the ebb-tidal delta of Mobile Bay (fig. 42). During this time, the southeastern shoreline of Dauphin Island was undergoing erosion.

From 1822-48, the ebb-flood tidal channel lengthened toward the south and deepened along its length as shown in 1848 (fig. 43). The deepening of the channel has not been linked to a hurricane. Sediment transport along the western margin of the ebb-tidal delta of Mobile Bay caused the northwestward migration of Pelican and Sand Islands by accretionary growth at their northern ends. Most of the southeastern shoreline of Dauphin Island is undergoing erosion in 1848 and Dauphin Island is no longer breached. The configuration of Dauphin and Pelican Islands in 1848 is almost identical to that seen in 1718.

Pelican and Sand Islands have migrated toward the southeast, and the ebb-flood tidal channel has deepened during 1848-92 (fig. 43). The deepening of the channel in 1892 (fig. 43) was probably caused by one or more of the eight hurricanes that inflicted damage to coastal Alabama over the period 1848-92. Nearshore sediment transport pathways in 1892 are southeastward, along the eastern side of the channel, and across the channel between the two deep channel endpoints (fig. 43). Sediment transport appears to have taken place along both the southern and northern shorelines of Pelican and Sand Islands. The southeastern shoreline of Dauphin Island was undergoing erosion in 1892.

By 1908, the ebb-flood tidal channel was almost completely filled with sediment derived from the Morgan Peninsula littoral drift system and erosion of channel margins. Pelican and Sand Islands have migrated and lengthened by accretionary growth at their northern ends. Sediment transport pathways in 1908 are virtually identical to the those of 1892 (fig. 43). The southeastern Dauphin Island shoreline was in a state of erosion during 1908. The hurricane of September 27, 1906, was probably responsible for infilling the ebb-flood tidal channel.

The ebb-flood tidal channel had deepened by 1918, returning to its 1892 configuration (fig. 43). Pelican and Sand Islands had diminished in size, with the pass between Pelican and Dauphin Islands becoming narrower and shallower. The main nearshore sediment transport pathway in 1918 appears to be southward, along the eastern margin of the channel, around the southern end of the channel, and northeastward along the western margin of the ebb-tidal delta of Mobile Bay, including Pelican and Sand Islands (fig. 43). A pass has separated the eastern one-third of Dauphin Island from its western two-thirds (fig. 43). The hurricane of July 5, 1916, or September 28, 1917, may have been responsible for scouring the ebb-flood tidal channel.

The 1920 bathymetric map (fig. 44) does not cover enough of the study area to determine nearshore sediment transport pathways that prevailed at that time. However, similarities between the 1918 and 1920 bathymetric maps (figs. 43, 44) suggest that the transport pathways were probably the same.

The 1927 bathymetric map (fig. 44) is virtually identical to those of 1918 (fig. 43) and 1920 (fig. 44). Dauphin Island was still breached by a pass in 1927, but a flood-tidal delta, present in 1918, no longer exists. Some accretion has occurred around the margin of the ebb-tidal delta of Mobile Bay, indicating nearshore sediment transport pathways around the margin of the ebb-tidal delta of Mobile Bay (fig. 44). The 1927 nautical chart indicates the presence of a channel (Mobile Bay entrance channel) dredged in 1925.

The 1941 bathymetric map covers only the ebb-tidal delta of Mobile Bay (fig. 44). The ebb-flood tidal channel has been partially infilled since 1927, and the Mobile Bay entrance channel has been dredged during 1927 to 1941. The infilling of a portion of the channel has permitted the main sediment transport pathway to shift northward in 1941 (fig. 44). Pelican Island has disappeared, Sand Island has grown into a crescent-shape, and Dauphin Island is once more a continuous island as it is today (1997).

The 1960 bathymetric map (fig. 44) covers only about a third of the study area. Some channel infilling has occurred north of the present-day State-Federal Boundary. Sand Island has grown into an elongate island and Dauphin Island is a continuous island as it was in 1941. The 1960 sediment transport pathways appear to be unchanged from 1941 (fig. 44).

The 1969 bathymetric map (fig. 45) shows that the northern and southern ends of the ebb-flood tidal channel has partly filled, and the deepest portion of the southern end of the channel have shifted toward the north. Pelican Island has also moved north and shows some growth at its northern end. Dauphin Island is in its unbreached state, as it appears today (1997). Sediment transport pathways in 1969 appear to be from Morgan Peninsula across the channel and through Pelican Bay to Dauphin Island (fig. 45). Some sediment moves from Morgan Peninsula, southeastward, around the southern margin of the ebb-tidal delta of Mobile Bay, then along Sand Island, and northerly to Dauphin Island.

In 1977, the ebb-flood tidal channel has returned to its 1960 configuration, Sand and Pelican Islands are absent, and Dauphin Island is a continuous island as it appears today (1997) (fig. 45). The channel was dredged, or perhaps scoured by Hurricane Camille (August 17, 1969). In 1977, sediment transport was from Morgan Peninsula, southward along the eastern margin of the ebb-tidal delta of Mobile Bay. Some sediment is transported northwestward along the western margin of the ebb-tidal delta of Mobile Bay, and on to Dauphin Island (fig. 45). The southeastern shoreline of Dauphin Island was in an accretionary state.

The configuration and placement of the ebb-flood tidal channel has not changed during 1977-87, except that the southern two-thirds of the channel is partially infilled with sediment derived by erosion of the surrounding sea floor (fig. 45). Pelican and Sand Islands are a series of five islands, and Dauphin Island is one continuous island as it is today (1997). Littoral drift and tidal current transported sediments from Morgan Peninsula and Mobile Bay move into the channel and appear to be flushed out of the channel by tidal currents to form a sediment apron in northeast area 4 (fig. 45). Some sediment from Morgan Peninsula crosses the channel and travels northwestward along the western margin of the ebb-tidal delta of Mobile Bay (fig. 45). Pelican Bay and southeastern shoreline of Dauphin Island are in an erosive state, probably due to the limited supply of sediments from Morgan Peninsula. Gulf of Mexico waves impinging on the western margin of the ebb-tidal delta of Mobile Bay, and lack of sediment supply have sculpted Pelican Island into thin, elongate islands, and steepened the shoreface by eroding the western margin of the ebb-tidal delta of Mobile Bay. Tidal currents flowing through the pass between Dauphin and Pelican Islands were responsible for erosion of the southeastern shoreline of Dauphin Island. The eroded sediments are being used by the littoral drift system to shallow and narrow the pass between Dauphin and Pelican Islands, and lengthen Pelican Island by accretion at its northern end. Hurricane Frederic (September 12, 1979) caused extensive damage to Mobile and Baldwin Counties. Dredging of the Mobile Bay entrance channel was required after the hurricane.

In 1997, the southern end of the ebb-flood tidal channel was deepened by dredging, Sand Island has diminished or disappeared, while Pelican Island has lengthened by accretionary growth at its northern end, developing a crescent shape (fig. 45). The U.S. Army Corps of Engineers constructed a nearshore berm in 1986. The pass between Dauphin and Pelican Islands has narrowed and deepened. The littoral drift system moves sediment from Morgan Peninsula southward along the eastern margin of the ebb-flood tidal channel to the southern apex of the ebb-tidal delta of Mobile Bay (fig. 45). Some sediment is deposited in the extreme northeastern corner of area 4, but it is not apparent how sediment moves around the apex and toward Dauphin Island. It appears that much of the sediment used to accrete the northern end of Pelican Island comes from the destruction of Sand Island and the southern end of Pelican Island (fig. 45). The southeastern shoreline of Dauphin Island is being eroded by tidal currents moving through the pass between Pelican and Dauphin Islands. Hurricane Danny (July 18, 1997) caused localized moderate beach and coastal dune erosion on the Dauphin Island and Morgan Peninsula Gulf of Mexico shoreline.

NUMERICAL MODELING

Hummell and Smith (1995, 1996) used vibracores, foundation borings, and bottom samples to delineate and characterize sand deposits within area 4, resulting in the discovery of a sand resource body with the potential to provide material for beach nourishment projects. Detailed laboratory analyses were performed on bottom, vibracore, and boring sediment samples to determine grain size characteristics and aesthetic quality. From this information, it was concluded by Hummell and Smith (1995, 1996), that the sand in the resource body met the specifications of beach sand quality and volume for use in nourishment of eroding Dauphin Island shoreline.

Before the area 4 sand resources can be recovered and utilized in a Dauphin Island beach nourishment project, numerical modeling studies need to be carried out to answer questions about the consequences of sand resource recovery, beach nourishment project design, and shoreline behavior in response to beach nourishment. This portion of the study completed task 3 of the project.

PREVIOUS NUMERICAL MODELING STUDIES

Numerical models for simulation of Mobile Bay system waters have undergone rapid development in the last ten years. Both improved model-formulation techniques and improved digital-computer capabilities have stimulated the increased use of, and confidence in, these models. The first-generation hydrodynamic models (April and Hill, 1974; April and Liu, 1975; April and Ng, 1976a, 1976b) were restricted to a constant spatial step size and fairly simple boundary conditions. For example, finite difference cells were either land or water with no provisions for "drying" or "flooding" of cells during the modeling process. Second-generation hydrodynamic models (April and others, 1975; April and Hu, 1979; Raney and others, 1984) introduced improved boundary conditions for the finite difference cells, including an inundation capability. Sub-grid features also allowed a description of a geometric feature smaller than the selected grid size. For example, a sand bar, smaller than a grid cell, might be represented by a sub-grid barrier restricting flow through one or both faces of the cell. State-of-the-art third-generation hydrodynamic models (e.g., Raney, 1984, 1985; Raney and Youngblood, 1987) introduced a variable spatial grid capability allowing a smaller spatial step, where required, for proper resolution of physical detail.

It is important to recognize that numerical modeling of hydrodynamic systems is not an academic exercise with little relationship to the physical world. Any computer model will provide an investigator with an answer to a question. However, the numerical hydrodynamic model, when properly applied and verified, is an extremely powerful predictive tool and a viable, cost effective alternative to physical (scale) modeling or extensive oceanographic data collection.

In order to establish representative monthly salinity and velocity distributions in Mobile Bay, Raney and others (1989a) applied a two-dimensional depth-averaged finite difference numerical model with average monthly boundary conditions. The numerical model was previously calibrated and verified using surface elevations, velocity, and salinities (Raney and others, 1989a). Average monthly tidal regimes, winds, and fresh water inflow were collected from the literature and provided by the Mobile District, U.S. Army Corps of Engineers. These average monthly values allow the establishment of required boundary conditions for the numerical model.

For each month of the year, a set of reasonable initial conditions was established and a 24-hour cycle of tide and river inflow boundary conditions was applied to the numerical model (Raney and others, 1989a). The long-term monthly average wind speed and direction was held constant in both magnitude and direction. The numerical model was run for a total of three cycles (72 hours). The first two cycles were used to establish essentially repetitive conditions in Mobile Bay with results presented for hours 48 through 72 of the numerical simulation. In Raney and others (1989a), representative velocity plots are presented at hourly intervals for each month of the year. The salinity contours are presented in a separate report (Raney and others, 1989b).

The numerical model results appear to be generally consistent with available data (Bault, 1972; Schroeder, 1976) for Mobile Bay. The movement of high salinity water up the main channel is very apparent in the monthly salinity contours. Figure 46 shows the 60 hours (ebb tide) and 72 hours (flood tide) for the months of January and July in the Gulf of Mexico southeast of Main Pass (Raney and others, 1989a).

HISTORY OF NUMERICAL MODEL APPLICATION TO BEACH NOURISHMENT PROJECTS

Numerical models are used to simulate nearshore hydrographic and sediment transport systems and the resulting change in shoreline position, configuration, beach sediment volume, and bathymetry. In general, these models subdivide the shoreline into a large number of individual cells or compartments. Equations are used to relate sediment transport to wave parameters and current velocities, and thereby, calculate the movement of sediment from one cell to the next. A continuity equation is used to ensure the conservation of sediment, so that no sediment is created or destroyed, but merely moves from one cell to the next. Therefore, any net loss or gain of sediment within an individual cell is expressed as net accretion or erosion of the shoreline. In general, sediment transport is treated as a vector. In the case of littoral drift transport along a beach, sediment moves at a given velocity in one direction, so sediment enters and leaves from the same sides in all the cells. It is the net accumulation or loss of sediment volume (measured over computer

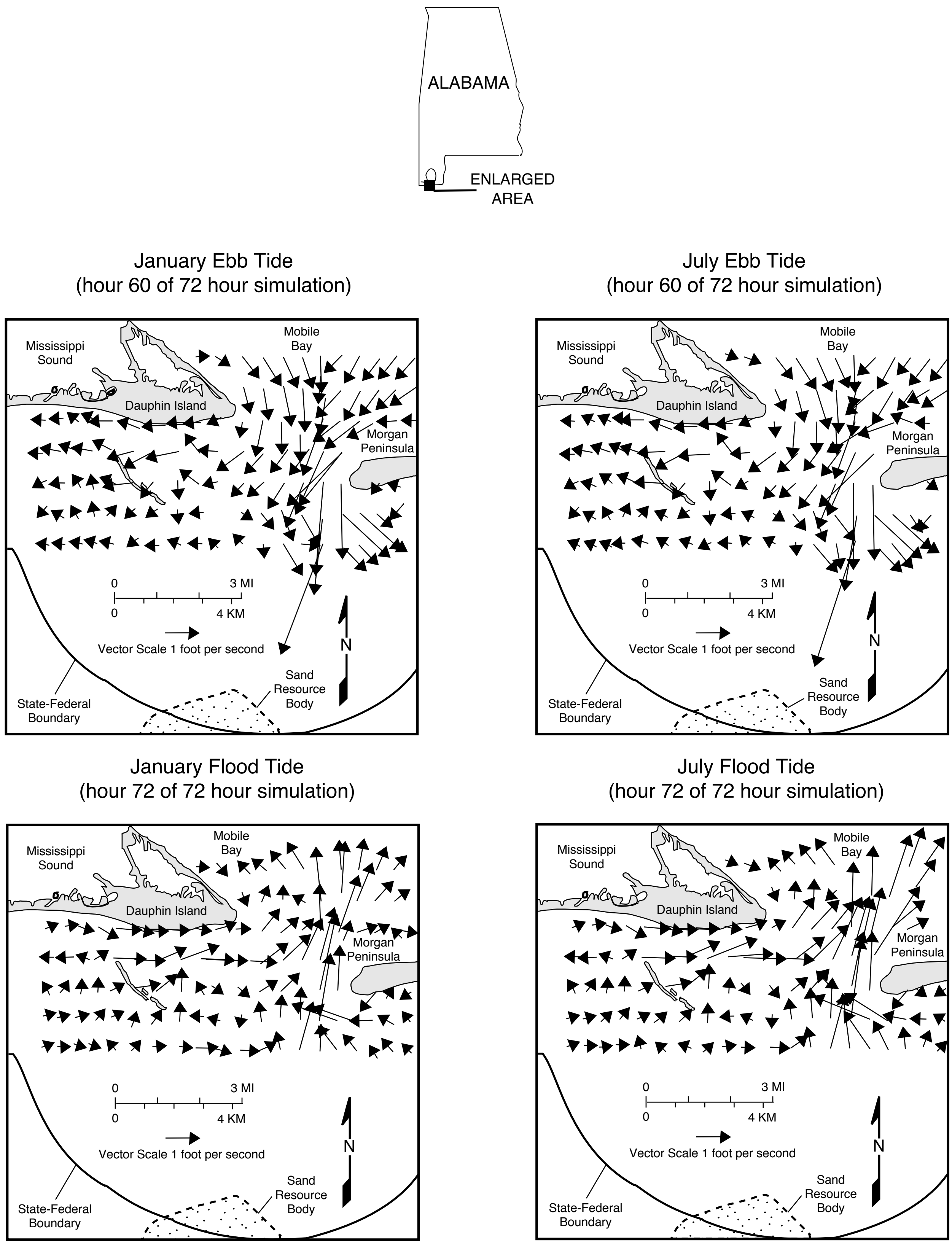


Figure 46.--Maps showing surface water velocity vectors generated by a two-dimensional, depth-averaged finite difference numerical model of average monthly conditions for January and July (modified from Raney and others, 1989).

time that simulates the passage of days, weeks, months, or years) from each cell that governs whether the shoreline will advance or retreat.

Price and others (1973), Komar (1973), and Perlin and Dean (1979) provide early examples of numerical computer modeling of shoreline change. Kriebel (1990) and Kriebel and Dean (1985) developed a computer model, EDUNE, to evaluate shoreline erosion due to storms. Larson and Kraus (1989, 1990) developed SBEACH during the period 1988-90. It is used to predict beach and dune erosion by storms. The model was further refined by Wise and Kraus (1993).

The erosion rate of a beach nourishment design is estimated by using historical erosion rates. Additional sediment (advanced fill) is added to the total volume of sediment that will be placed on the beach to account for the loss of sediment between beach nourishments. Also, a quantity of sediment is built into the beach nourishment design to cover the loss of beach nourished sediment to adjacent beaches (end loss). Building on the work of Bakker (1968), Perlin and Dean (1979), and Dean (1983) developed an analytical model to predict nearshore bathymetric changes due to longshore and cross-shore loss of sediment on a nourished beach. Hanson and Kraus (1989) developed a shoreline numerical model, GENESIS, for application to beach nourishment projects.

NUMERICAL MODELING APPROACH

The numerical modeling approach adopted by GSA and ChE was to model hydrography and sediment transport for area 4 and begin modeling southeast Dauphin Island shoreline in the present study, and conclude the modeling of Dauphin Island in the next project year. The GSA submitted to ChE modeling goals, objectives, needs, and questions, which were used by ChE in the numerical model selection process. In addition, the modeling database assembled by

Hummell and Smith (1995, 1996) provided ChE with additional criteria for selection of candidate models. Candidate models were evaluated by GSA and ChE with respect to the feasibility of acquiring any additional data needed to run the numerical model, and historic data to verify the modeling results. Once GSA and ChE selected a numerical model, GSA proceeded to construct the verification database, and ChE set about collecting the additional data needed to operate the numerical model. The GSA provided ChE with a list of contacts that can provide numerical modeling data, expert advice, technical support, and software. After ChE achieved an operational numerical model, GSA's historic database would be used to evaluate the modeling results to determine if the model adequately described the present day hydrographic and sediment transport systems of area 4 and southeastern Dauphin Island shoreline. If so, the numerical model would be run in reverse and the modeling results compared to the historic database to determine if the model accurately described the hydrographic and sediment transport systems as they were known to exist at various times in coastal Alabama history. Through an iterative process involving comparison of the historic database to the modeling results, adjustment of the numerical model, and recomparison of the historic database to the adjusted modeling results, working numerical models would eventually be developed that separately model the hydrographic and sediment transport systems for area 4 and southeastern Dauphin Island shoreline. The working models could then be used to provide information and address questions about sand resource recovery and beach nourishment.

NUMERICAL MODELING GOALS, OBJECTIVES, NEEDS, AND QUESTIONS

The GSA formulated the following information to be addressed in numerical modeling studies area 4 and southeastern Dauphin Island shoreline.

ALABAMA PROJECT GOALS AND OBJECTIVES

(1) Assist ChE in completing baseline physical databases for area 4, and nearshore southeastern Dauphin Island.

(a) Assist ChE in obtaining pre-existing Gulf of Mexico wave database from U.S. Army Corps of Engineers.

(2) Assist ChE in developing a working numerical model of the hydrographic and sediment transport systems for area 4.

(a) Construct bathymetric and bathymetric differencing database for area 4.

(b) Conduct a preliminary investigation of historic tropical storms and hurricanes that have affected coastal Alabama.

(c) Conduct a preliminary investigation of historic channel dredging and dredged material disposal in coastal Alabama.

(3) Assist ChE in beginning to develop a working numerical model of the hydrographic and sediment transport systems of nearshore southeastern Dauphin Island.

(a) Construct bathymetric and bathymetric differencing database for nearshore southeastern Dauphin Island.

(b) Conduct a preliminary investigation of historic tropical storms and hurricanes that have affected coastal Alabama.

(c) Conduct a preliminary investigation of historic channel dredging and dredged material disposal in coastal Alabama.

ALABAMA PROJECT NEEDS AND QUESTIONS TO BE ADDRESSED BY WORKING NUMERICAL MODELS

(1) Utilize research products to design a sand resource recovery project.

(a) Predict temporary (short and long-term) and permanent changes to the borrow site.

(b) What will be the characteristics and behavior of a sediment plume generated by sand resource recovery?

(c) Will sand resource recovery at the borrow site impact the rest of area 4?

(d) Predict storm history at area 4 over the life of the beach nourishment project.

(e) Determine dredge pattern, locations, and volumes of sand to be removed.

(f) What are the consequences of periodic removal of sand resources from area 4 over the life of the beach nourishment project?

(g) Will removal of sand aggravate the southeast Dauphin Island shoreline erosion problem?

(h) Does area 4 afford storm protection to Dauphin Island, and if so, will that protection be compromised by sand resource recovery?

(i) Evaluate competing sand resource recovery project designs.

(j) How will sand resource recovery affect physical environmental conditions?

(k) Predict temporary (short and long-term) and permanent changes to the biological system of the borrow site and the rest of area 4.

(l) Will the sand resource recovery project affect the recreational and commercial fishing, and the seafood industry?

(2) Utilize research products to design a beach nourishment project for southeastern Dauphin Island.

(a) Predict future erosion rates, shoreline change, and overall sand longevity along the proposed beach nourishment shoreline.

(b) What will be the characteristics and behavior of a sediment plume generated by sand placement?

(c) Predict storm history over the life of the beach nourishment project.

(d) Determine locations and volumes of sand; beach slopes and width; need for, type, and placement of man-made structures; and local sand longevity.

(e) Predict what the nourished beach will look like after shoreline equilibrium is established.

(f) Will the nourished beach reduce the physical damage to the shoreline by storm waves and surge?

(g) Develop a renourishment schedule.

(h) Estimate the cost over the life of the beach nourishment project.

(i) Evaluate competing beach nourishment project designs.

(j) How will sand placement affect physical environmental conditions?

(k) Predict temporary (short and long-term) and permanent changes to the biological system along Dauphin Island.

(l) Will the beach nourishment project affect the recreational and commercial fishing, and the seafood industry?

(3) Utilize research products to establish stations for an area 4 and southeastern Dauphin Island beach nourishment monitoring program.

(a) Operational and performance monitoring.

(b) Collection of physical, biological, and environmental data before, during, and after sand resource recovery and placement.

(c) Storm event monitoring.

(d) Continued refinement of numerical models.

(e) Better understanding of physical and biological systems.

NUMERICAL MODELING RESOURCES

OCEANOGRAPHIC DATA AND SATELLITE IMAGERY

Dr. Jonathan R. Pennock
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GULF OF MEXICO WAVE DATABASE AND

GENESIS SOFTWARE, INSTRUCTIONS, ADVICE, AND SUPPORT

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APPLICATION OF NUMERICAL MODELS:

GENESIS, SBEACH, AND OTHERS

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THEORY AND EXTENSION OF NUMERICAL MODELS:

GENESIS, SBEACH, AND OTHERS

Dr. Robert G. Dean
Chairman and Graduate Research Professor
Department of Coastal and Oceanographic Engineering
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Gainesville, FL 32611

THREE-DIMENSIONAL NUMERICAL MODELS

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NUMERICAL MODEL SELECTION

Based on the criteria outlined above, the GSA and ChE initially selected GENESIS as the numerical model that might best serve the needs to model the hydrographic and sediment transport systems of the nearshore southeastern Dauphin Island area. Additional factors that led to the decision to choose GENESIS include being able to run the software on personal computers; availability of user's manuals (Hanson and Kraus, 1989; Gravens and others, 1991); technical support by the U.S. Army Corps of Engineers, the developers of GENESIS; availability of numerous researchers and research project reports that have used GENESIS; and researchers are engaged in the study of the models limitations and ability to be extended to a variety of beach nourishment applications. The Committee on Beach Nourishment and Protection (1995) site GENESIS's successful track record of accurately predicting the outcome of a beach nourishment project, predicting erosional hot spots, simulating hydrographic and sediment transport systems of soft (sediment) and hard (natural rock or man made structures, such as, groins, jetties, sea walls, etc.) shorelines, determining future shoreline configuration, and mimicking the behavior of borrow sites.

One of the chief advantages in using GENESIS is its flexibility. It can calculate wave transformations as they shoal and undergo refraction and diffraction, calculate the patterns of longshore sediment transport, and then determine the resulting shoreline changes. The latest versions of the software can calculate longshore sediment transport rates, including transport caused by waves breaking obliquely to the shoreline and longshore variations in wave breaker heights. This capability allows modeling of soft and hard shorelines or a mixture of the two types. GENESIS is capable of analyzing wave refraction in the nearshore and offshore, enabling the software to model offshore areas, like area 4, and offshore borrow sites in sand recovery projects.

AREA 4 NUMERICAL MODELING

After accomplishing the initial steps toward making GENESIS operational, and with further research on the numerical model, it was concluded by ChE, that GENESIS would not be robust enough to handle the complex hydrographic and sediment transport systems found in the study area. The presence of tidal currents through Main Pass, the ebb-tidal delta of Mobile Bay, Pelican and Sand Islands, and Mobile Ship Channel, produces a complex hydrographic and sediment transport setting in nearshore southeast Dauphin Island.

The second choice, a multi-layered, three-dimensional model POM (Three Dimensional, **P**rimative Equation, Numerical **O**cean **M**odel), is currently being evaluated by ChE. The ChE will make the numerical model operational using the modeling database generated by Hummell and Smith (1995, 1996), bathymetric and bathymetric differencing database, preliminary historic channel dredge and dredged material disposal information, and preliminary historic tropical storm and hurricane data from the present report, and other databases. The model will then be used to simulate the present-day hydrographic and sediment transport systems of area 4 and southeastern shoreline of Dauphin Island.

SUMMARY AND CONCLUSIONS

The objectives of this study were accomplished through the completion of the three tasks outlined in the "Introduction". These tasks further evaluated the sand resource potential of area 4 for use as beach nourishment on eroding southeastern Dauphin Island shoreline segments. The specific outcomes for these tasks include:

1. Networking was continued as a mechanism to involve agencies in the process of developing a recommendation for a beach nourishment project. This task was accomplished by hosting the *MMS Coordination Meeting: Environmental Survey of Identified Sand Resource Sites Offshore Alabama*, attendance at the Technical

Interagency Committee Meeting, holding meetings with coastal research groups, and conducting post-Hurricane Danny coastal shoreline damage assessment ground surveys.

2. Development of a modeling database was continued by obtaining and evaluating any available relevant pre-existing geoscience data within the budget constraints of the study. A Gulf of Mexico wave database that was compiled by the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, was identified by Hummell and Smith (1996), but they did not obtain the database at that time, not knowing what portion of the extensive database would be needed for future numerical modeling studies. The ChE is currently in the process of obtaining the pertinent portion of the wave database for use in numerical modeling studies.

The GSA conducted preliminary studies of historic hurricanes and tropical storms that affected coastal Alabama, and historic channel dredge and dredged material disposal activities.

Historic records show that over the period 1700-1997, 55 hurricanes and 16 tropical storms affected the Alabama coast. Seven to 15 hurricanes are thought to have changed the geomorphology and bathymetry in the study area.

In 1826, the federal government began improvements to the Mobile Bay ship channels, and through the years the channel depths and widths kept pace with the increasing size of vessels using the Port of Mobile.

The bathymetric and bathymetric differencing maps chronicle a cycle of geographical and bathymetric change that has occurred in the study area between 1732 and 1997. The interplay between coastal geography, bathymetry, ebb-flood tidal channel dredging, scouring, and filling, punctuated by hurricanes and tropical storms, dictates nearshore sediment transport pathways, nearshore Gulf of Mexico wave orientation, patterns of shoreline erosion and accretion, and nearshore tidal current velocity. Except for brief periods of erosion or deposition that caused bathymetric changes of a few feet, the overall bathymetry of area 4 has not changed appreciatively over the past 265 years.

The results of this study show that the depth and length of the ebb-flood tidal channel are the primary factors in determining nearshore sediment transport pathways. In general, when the channel is deep and extends from Morgan Peninsula to the southern apex of the ebb-tidal delta of Mobile Bay, the channel acts as a barrier to sediment transport from the Morgan Peninsula Gulf of Mexico shoreline across Main Pass to Dauphin Island Gulf of Mexico shoreline. In this case, the dominant nearshore sediment transport pathway is from Morgan Peninsula southward along the eastern margin of the ebb-tidal delta of Mobile Bay, around the southern apex of the delta, and northwestward, along the western margin of the delta (and Pelican and Sand Islands) to Dauphin Island. When the ebb-flood tidal channel is relatively shallow and short or discontinuous, nearshore sediment transport is primarily from Morgan Peninsula westward through Pelican Bay to Dauphin Island. Most of the time over the past 265 years, both sediment transport pathways have been operational, but always one pathway is dominant over the other. During times when the sediment transport pathway from Morgan Peninsula is directly west to Dauphin Island, most of the southeastern shoreline of Dauphin Island is in a state of accretion. Sediment starvation, brought about by the main nearshore sediment transport pathway following the margin of the ebb-tidal delta of Mobile Bay, results in a state of erosion for most of the southeastern Dauphin Island shoreline. If both pathways are active, even though the ebb-tidal delta of Mobile Bay pathway is dominant, there may be enough sediment in transport along the direct, westward route, to keep the southeastern Dauphin Island shoreline stable or accretionary.

Sediment obtained from the Morgan Peninsula littoral drift system and tidal current erosion of channel margins is used by the study area hydrographic system to infill the ebb-flood tidal channel. In general, hurricanes and dredging of the Mobile Bay entrance channel over the past 74 years is responsible for deepening and lengthening the ebb-flood tidal channel.

3. The ChE is currently in the process of making a multi-layered, three-dimensional model operational. GSA and ChE worked together to identify and assess numerical models that might be supported by the database, the existence of other models and additional databases needed to adapt them to these systems, and the outcomes that might form the goals of this project based on the model and database decisions identified.

In addition, GSA formulated goals, objectives, needs, and questions that must be satisfied in the modeling study; evaluated the completed database and made recommendations regarding the kinds of modeling output that is desired to meet initial goals and objectives; and participated in ranking the available models that are supported by the modeling database and making selections based on meeting stated goals and objectives. The results of the GSA's studies of historic hurricanes and tropical storms that affected coastal Alabama and historic channel dredge and dredged material disposal activities will be used by ChE in developing a working model of the hydrographic and sediment transport systems of area 4 and southeastern Dauphin Island shoreline. The historic bathymetric and bathymetric differencing maps produced by GSA, in conjunction with the research findings of Hummell and Smith (1996), will be used by ChE in the following ways: (1) select case studies designed to test the validity of the numerical model; (2) evaluate the results of modeling studies; (3) investigate changes that might be made in the model that would improve the ability of the model to approximate system behavior; (4) participate in testing the model for a series of system variable changes deemed applicable to the physical system (including current flow, sediment loading, and wind forces); (5) draw conclusions and make recommendations for beach nourishment project design; and (6) determine the need for continued modeling studies or studies to collect additional data.

RECOMMENDATIONS

HISTORIC HURRICANES AND TROPICAL STORMS

Periodic high energy events, such as hurricanes and tropical storms, need to be incorporated into numerical models of the hydrographic and sediment transport systems in area 4 and southeastern Dauphin Island shoreline. It is recommended that those historic hurricanes identified by GSA in the present study as having more than a minimal impact to coastal Alabama, be researched more extensively by GSA to provide a detailed account of each storm. The trackline of the storm in coastal Alabama; meteorological and hydrographic data; storm surge, tide, and rainfall data; and shoreline damage and change information would be useful in developing a working numerical model that incorporates periodic hurricanes.

HISTORIC CHANNEL DREDGING AND DREDGED MATERIAL DISPOSAL

During the preliminary investigation of historic channel dredging and dredged material disposal in coastal Alabama, an extensive collection of documents was located by GSA that can provide additional information. Examination and analysis of these documents is beyond the time constraints of the present study. It is recommended that these documents be reviewed by GSA to determine the dates and locations of historic dredging and dredged material disposal in the study area.

DAUPHIN ISLAND SHORELINE PROFILES

Parker and others (1993) determined the character of the erosion that has occurred on the southeastern Dauphin Island Gulf of Mexico shoreline since 1955. Hummell and Smith (1995, 1996) included estimation of sand volumes necessary to restore southeastern Dauphin Island Gulf of Mexico beaches eroded during the 11-year period 1985-96. These data were intended to supplement previously derived estimates by Parker and others (1993) of the sand volume required to restore southeastern Dauphin Island beaches eroded during the 30-year period 1955-85. In the aftermath of Hurricane Danny, it is advisable that GSA conduct ground surveys to update erosion rates and the estimates of sand volumes required to restore and stabilize southeastern Dauphin Island eroding shoreline segments delineated by Parker and others (1993). In addition, the numerical model will need to be calibrated with historic southeast Dauphin Island shoreline change, so that it can faithfully represent the causes of the background erosion. The GSA's shoreline profile database will need to be synthesized by GSA into a form that can be used by the numerical model.

HURRICANE DANNY AND SEDIMENT PLUMES

Hummell and Smith (1995) evaluated area 4 for its sand resource potential. They documented the geologic framework and lithofacies patterns of this area and delineated a sand resource body that has sand resource potential. Hummell and Smith (1996) collected additional surface and subsurface information to more completely document sand body geometry and granulometry. As mentioned in the text of the present report, spring 1997 high freshwater discharge of the Mobile-Tensaw River system formed sediment plumes that deposited fine-grain sediments in areas 4 and 5. Additionally, Hurricane Danny may have affected area 4. The GSA recommends that several additional sea floor samples and vibracores be collected by GSA in area 4 to determine the impact of the sediment plumes and hurricane on the sand resource body.

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